SUMMATIVE EVALUATION

TOO SMALL TO SEE

Summative Evaluation Report

For a Science Museum Exhibition on Nanotechnology Education

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Traveling Museum Exhibition Introduces Nanotechnology

Too Small to See is a 5,000-square-foot interactive museum exhibition designed to “zoom” visitors’ imaginations into the world of nanotechnology. The exhibition was funded by the National Science Foundation (NSF) and developed by Cornell University with the Sciencenter of Ithaca, NY and Painted Universe Inc. The project’s primary goal is to help visitors understand how scientists see and make things that are too small to see.

Too Small to See (TSTS) opened at Innoventions at Epcot® in November 2006, where an estimated one million visitors toured the exhibition from November 2006 through May 2007. *TSTS* will travel to several museums across the country during the next five years and is expected to reach an additional two million visitors during its national tour. It is currently booked through May of 2009.

AT DISNEY’S EPCOT® an estimated one million visitors toured *Too Small to See*. Hands-on exhibits and multimedia stations introduce children, teens and adults to nanotechnology.

Designed to offer an interactive experience for children ages 8 to 13 and adults, *Too Small to See* introduces science concepts underlying nanotechnology and nanotechnology applications. The exhibition surrounds visitors with enlarged models of atoms, molecules, and other nanoscale objects. Interactive exhibits let visitors experience or visualize technology at the nanoscale.

Among the exhibition’s 16 different exhibits are multimedia stations that present stories of discoveries in nanotechnology. Content for those stations is provided by *Earth and Sky*—an award-winning international science-news radio program. In addition to the displays, exhibits, and multimedia stations, *TSTS* includes supplemental materials to help museum educators provide programming and teacher support for the exhibition. A web site (www.toosmalltosee.org) offers information about *Too Small to See*’s development and related learning materials.

This evaluation examines the exhibition’s outcomes and impact on increasing visitors’ awareness of, interest in, engagement with, and understanding of nanoscale science, engineering, and technology. An overarching goal is to document the project’s contribution to the portfolio of federally funded Science Technology Engineering and Mathematics (STEM) projects through Informal Science Education (ISE). A second goal is to provide information for professionals in the NISE Network (Nanoscale Informal Science Education) funded by NSF’s Nanoscale Science and Engineering Education (NSEE) program.

This summative evaluation presents evidence-based findings to gauge the funded project’s effectiveness. A summary of the evaluation methodology, questions, and audience sample follows. *What was Produced?* documents the project’s deliverables. *What was Learned?* presents evaluation findings and documents lessons learned. *What was the Impact?* presents further evidence to support findings.

THIS REPORT PRESENTS FINDINGS from external evaluation of *Too Small to See*—a 5,000-square-foot interactive museum exhibition developed by Cornell University to increase public understanding of nanoscale science and nanotechnology. The National Science Foundation (NSF) provided funding for *TSTS* for five years through the Informal Science Education program (Award Number ESI-0426378) under the Directorate for Education & Human Resources. This is the final external evaluation report for this project; it synthesizes data on project activities from June 2004 through September 2007.

Methodology

The Evaluation Study

From June 2004 until October 2007 Edu, Inc. served—under contract to Cornell University—as external evaluator for Too Small to See. *Edu, Inc. assisted with education planning and exhibit development, and performed the exhibit's museum-setting evaluation.*

The overarching purpose of evaluation was to document the intellectual merit and broader impact of *TSTS*. Specifically:

1. What does the typical person know about nanoscale science and nanotechnology?

2. What is the evidence that *Too Small to See* helped increase visitors' awareness and understanding of, and interest in, nanoscale science and nanotechnology?

3. What questions about nanotechnology do visitors want answered?

4. To what extent do models and visualizations engage visitors and represent nanoscale objects and products of nanotechnology?

5. How effective is interpretive media in communicating nanoscale science content and nanotechnology applications?

6. To what extent is the exhibition accessible to underserved audiences—those with disabilities, ethnic minority communities, and girls?

7. Is the exhibition safe, durable, and marketable?

8. What is the sustained impact of *Too Small to See* in the absence of NSF funding?

EVALUATION: appropriate methods

Recognizing that randomized control trials and quasi-experimental methods are considered by many the most rigorous of study designs, evaluators selected a less rigorous, but appropriate and revealing methodology.

Pre-visit and post-visit interviews with a comparison group, tracking studies, and other methods blended precise quantitative and rich qualitative data to test new methods in nanotechnology education.

FIGURE 1 Evaluation Findings

EVALUATION FINDINGS

- Peer-reviewed front-end research shows most members of the public do not understand nano-scale science content and are not familiar with nanotechnology.
- The public shows interest in nanotechnology. Seventy percent of adults and children interviewed during the summative study say they want to clearly understand "what nanotechnology is" and "how it is used." (n=105 of 150)
- Continual contact with the potential audience—inside and outside the museum—helped the *TSTS* team understand what visitors know, can learn, and are interested in.
- Rigorous formative evaluation—including concept testing, storyboards, triage, and exhibit prototyping—was essential to eliminating over 100 exhibit ideas that did not work well.
- Learning goals and controlled vocabulary allowed links to standards-based formal education.
- After using the exhibition, 70 percent of visitors in post-visit interviews used nanoscience vocabulary from the exhibition and showed increased understanding of and interest in nanotechnology.
- Visitors said they wanted to learn more about nanotechnology applications for medicine, electronic gadgets, and environmental sustainability.
- Chronic misconceptions about nanotechnology persist, including confusion about terms such as nanobot, nanochip, nano camera, iPod nano, nano pill, and "a nano."
- Mediation by explainers increased visitor interest and content acquisition. When trained explainers at Epcot talked with visitors those visitors stayed longer and showed more interest in and understanding of nanotechnology in exit interviews.
- Exhibits using hands-on models and visualization proved popular. Timing and Tracking and Sweeps show these exhibits used by over 60 percent of visitors for long periods of time. At Epcot, visitors returned later in the day to use these exhibits again—often for longer than initially.
- The *Carbon Nanotubes* exhibit—a children's play area built around giant renditions of carbon nanotubes—acted like a museum artifact or sculpture providing older youth and adults an easy to understand, larger than life example of a nanotechnology application.
- 70 percent of visitors used multimedia kiosks, but only on average for 30 seconds. Youth requested short, upbeat multimedia messages that are "cool enough for kids."
- The project benefited from collaboration between formal and informal education—Cornell University and the Sciencenter, respectively. Beyond *TSTS* the Sciencenter is collaborating with the NISE Network.

Evaluation Stages

Evaluation took place in three stages—front-end, formative, and summative—as described in detail below.

Front-end research in 2004 included a national survey of 1,500 people, ages 6 to 74, to determine the public's preexisting knowledge of the science underlying nanotechnology. These findings were published in a peer-reviewed journal (see: Waldron, Spencer, Batt, 2006).

Rigorous **formative evaluation** and ISE's best practices guided the project team in developing and evaluating potential *TSTS* exhibit ideas. From 2005 to 2006 the team tested prototype exhibits, signs, and interpretive media with potential visitors using storyboards, interviews, and web-based focus groups. The team consulted with cultural advisors—African American, Latino, and Native American community leaders, teachers, and clergy—as a

EVALUATION:
three stages

Front-end research showed what the public knows about nanotechnology. Formative evaluation tested exhibit ideas. Summative evaluation investigated the project's outcomes and impact.

TABLE 1 Evaluation Methods

STAGE	METHOD	SAMPLE SIZE	DESCRIPTION
Front-end	National survey of public "nanoliteracy"	1,500	National survey conducted in schools, museums, and with the general public in five states.
Formative	Storyboards and prototype testing; focus groups and interviews	2,000+	Internal and external evaluators conducted simultaneous and independent formative evaluation in museums, schools, and with the general public.
Summative	Pre-visit and post-visit interviews	150	Interviews assessed changes in visitors' awareness and understanding of and interest in nanoscale science content and nanotechnology.
Summative	Tracking study	75	Evaluators recorded which exhibits visitors used, in what order, and for how long.
Summative	Sweeps	10	Count of people at each exhibit taken once every hour. Total: 10 counts.
Summative	Naturalistic observation and short interviews	50	Unobtrusive observation followed by short interviews at hands-on model exhibits (*Build a Molecule* and *Build a Carbon Nanotube*) and visualization exhibits (*Magnification Station* and *Zoom into Nano*).
Summative	Observation of multimedia and signs	50	Observation of visitors using multimedia kiosks and signs.
Summative	In-depth interviews with explainers	20	Documented explainers' observations and insights about visitors' use of the exhibition; explored role of training to prepare explainers to help guests understand nanotechnology.
Summative	Pre-teaching mini-study	25	The picture book *What is Nanotechnology?* exposed 25 visitors to the exhibition's main ideas before they used the exhibits. Evaluators compared these guests' post-visit understanding of "nano" topics with that of visitors who did not read the picture book.

means to identify the needs of ethnic minority communities. An advisory group of teachers and female scientists helped the team to promote gender equity. Professional and volunteer disability advisors evaluated the exhibition for accessibility by those with disabilities. An advisory group of scientists, museum professionals and industrial leaders also helped guide the project.

Summative evaluation investigated the project's outcomes and impact, its outreach to underserved audiences, and its accessibility for those with disabilities. It also considered the exhibition's safety, durability, and marketability, and examined sustainability beyond NSF funding. Three evaluators from Edu, Inc. conducted a four-day site visit at Innoventions at Epcot in April 2007 and a two-day site visit at the Sciencenter in Ithaca, NY, in June 2007. An evaluator made a one-day follow-up visit to the Sciencenter in September 2007 to document all completed exhibits.

***TOO SMALL TO SEE* MET AND EXCEEDED** promised deliverables. The five-year development and deployment of *TSTS* resulted in front-end baseline data (published in a peer-reviewed journal, noted above); rigorous, replicable formative-evaluation techniques; exhibits and interactive media; and outreach to underserved audiences.

Publication, Exhibits, Programs

Hands-on Learning

TSTS is a self-directed and hands-on learning experience. The exhibition was developed with science-museum visitors in mind—children ages 8 to 13, other teens, adults, and family groups. Its development was guided by clearly defined learning goals and extensive field-testing of exhibits and educational materials. *TSTS*'s content is grouped into three educational domains: size and scale of sub-atomic particles; models and visualizations of nano structures; and nanotechnology applications.

A clear, concise, and coordinated interpretive strategy communicates key vocabulary terms and messages through signs, banners, multimedia kiosks, and large-format projection. Educational materials for museum educators and teachers provide extra programming and support.

Front-end Research and Formative Evaluation

To involve learners in the planning phase, the project team and external evaluator conducted simultaneous and independent evaluations of storyboards, prototype exhibits, titles, signs, and interactive interpretive media. The project enlisted teachers and science communication experts to evaluate interpretive materials including reading level, font choice, color, layout, and message length. This helped ensure

CONTINUAL CONTACT with the public provided an on-going reality check. Internal and external evaluators tested exhibit ideas inside and outside the museum. Edu, Inc. did over 200 “person in the street” interviews with teens at skateboard parks and families at video stores.

MUSEUM EXHIBITS:
learning goals

Hands-on science exhibits introduce children and families to nanoscale science and nanotechnology.

An interpretive strategy communicates key vocabulary, messages, and ideas.

PROMISED IN PROPOSAL	PRODUCED AS OF OCTOBER 2007
3,500 square foot exhibition	5,000 square foot exhibition
Front-end research about perceptions of nanotechnology	Front-end research about perceptions of nanotechnology completed and published
Front-end research about models	Front-end research about models completed
Formative exhibit evaluation	Formative exhibit evaluation completed
Summative exhibit evaluation	Summative evaluation completed and report released
Peer-reviewed publications and reports	Article published in *Journal of Nanoparticle Research* in July 2006
Web site	www.toosmalltosee.org
Lesson plans	Education materials developed by the Sciencenter in collaboration with Cornell University and NISE Net partners. Educator's guide, seven museum activity kits, list of national science education standards addressed by exhibits, and classroom activities.
Children's book	Focus groups with children completed; Children's books from the trade made available in the exhibition.
Tour to include geographically diverse museums and to encourage particular audiences	Tour at Epcot completed; 4 tour locations booked: Exploration Place, Wichita, KS; Danville Science Center, Danville, VA; Louisville Science Center, Louisville, KY; Boonshoft Museum of Discovery, Dayton, OH
Beyond proposal - underserved audiences	*Too Small to See Two* – a 1,500 square foot mini-exhibition funded for travel to museums in California and Texas serving underrepresented audiences
Beyond proposal - permanent exhibition	Negotiations underway for a permanent exhibition at Epcot to sustain impact beyond the project's end

TABLE 2 Promised versus Produced: TSTS exceeded proposed deliverables.

exhibits, signs, and media content were interesting and developmentally appropriate, and also supported multiple cognitive levels and learning styles.

Rigorous formative evaluation and continual contact with users provided audience feedback to guide development of the exhibition, its interpretive strategy, and the interactive media.

Lessons for the ISE Field

A carefully designed and repeatable summative evaluation study—blending quantitative and qualitative methods—produced lessons for the field. The study, conducted at Disney's Epcot and the Sciencenter in Ithaca, NY, included 150 pre-post interviews, a tracking study of 75 people, 100 short interviews, 50 interviews with people who used multimedia kiosks, and naturalistic observation around key exhibits. Interviews with 20 explainers at Epcot investigated the role of adult education in quickly preparing (training) explainers to work with visitors.

Exhibits

The project produced a 5,000-square-foot traveling exhibition and an interpretive strategy to communicate a set of core concepts in nanoscale science and nanotechnology applications through 16 hands-on museum exhibits. The exhibits focus on models and visualizations.

Interactive Media

Four multimedia kiosks combine video produced by the project team with audio content produced by *Earth and Sky*. An audio-only media station and a short video near the entrance introduces nanotechnology topics.

Access for Underserved Audiences

Understanding that audience diversity is a central tenet of NSF-sponsored programs, evaluators paid special attention to the exhibition's success in engaging ethnic minority communities, persons with disabilities, and girls. Multi-cultural and disability advisors guided the *TSTS* team. The project formed three advisory groups: One, a multi-cultural team including African American, Latino, and Native American community leaders, teachers, and clergy; two, a disability team of professional and volunteer disability advisors; and three, a team consisting of teachers, women scientists, and young women with experience promoting gender equity.

Visitors often used exhibits in groups.

Beyond the scope of the funded proposal, the project leaders and designers developed a second, smaller (1,500 square foot) exhibition containing six exhibits and several multimedia kiosks from the exhibition to accommodate small museums in underserved communities. Signs are bilingual (Spanish/English). The project funded the

"Multi-cultural and disability advisors guided the TSTS team"

second exhibition's installation at the University of California, Santa Barbara, and is seeking funding to place *TSTS-2* in museums serving underrepresented populations at little or no cost to the museum.

Sustained Impact

To sustain impact beyond NSF's funding period, final arrangements are being negotiated for the installation of a 1,500-square-foot permanent exhibition at Disney's Epcot that will serve an estimated one million visitors per year. In addition, the Sciencenter reports it has signed lease agreements from four museums through spring of 2009.

SUSTAINABILITY: beyond NSF funding

TSTS is booked until 2009; a second smaller exhibition for under-served audiences has been completed; and a potential permanent exhibition at Epcot is being negotiated.

Many visitors viewed photos of researchers and high technology like an art gallery. Several times evaluators observed ethnic minority girls bringing friends from another exhibit to see a photo of a non-Caucasian female scientist.

IN RECENT INTERVIEWS WITH ISE PROFESSIONALS and evaluators working on projects funded by the NISE Network, Edu, Inc. found that science-museum professionals are seeking answers to the same fundamental questions faced and answered by the *TSTS* project team as it began this project. This section presents eight evaluation questions followed by findings and the lessons learned.

Lessons Learned for NISE Network and the ISE Field

Evaluation Questions

These five primary questions guided the TSTS *study. They are examined in detail below.*

1) What do people already understand about nanoscale science and its applications?

2) How do people come to understand nanoscale-science concepts and structures?

3) What questions about nanotechnology do visitors want answered and what topics do they find most relevant?

4) What is the efficacy of models and other visualization tools to portray nanoscale objects, convey "nano" concepts, and explain nanotechnology applications?

5) How effective are interpretive media in communicating nanoscale-science concepts and nanotechnology applications?

In addition, the study answered three specific questions about the exhibition:

6) To what extent is the exhibition accessible to underserved audiences—those with disabilities, ethnic minority communities, and girls?

7) What is the sustained impact of *TSTS* in the absence of NSF funding?

8) Is *TSTS* safe, durable, and marketable as a traveling exhibition?

1) What do people already understand about nanoscale science and its applications?

From the project's inception, *TSTS* benefited from front-end research and rigorous formative evaluation.

Continual contact with museum visitors helped the *TSTS* team understand what visitors already know, what interests them, and how much new information can be retained.

FIGURE 2 Most People Do Not Understand Nanotechnology

MOST PEOPLE DO NOT UNDERSTAND:

- The terms atom, molecule, DNA, nano, nanometer, nanotechnology
- That a nanometer measures things you cannot see
- The comparative scale of subvisible objects (e.g., atom is smaller than molecule, molecule is smaller than a virus, a virusis smaller than a cell)

Sixty percent of those interviewed had not heard of nanotechnology

See references 2, 3, 4, 5

Front-end research sponsored a national study of 1,500 people age 7 to 74 which showed the public is largely uninformed about nanoscale science and nanotechnology.

What we found

Formative evaluation was critical to eliminating ideas, concepts, and exhibits that people did not understand. The process included:

- Internal and external evaluators conducted simultaneous and independent formative studies inside and outside the museum.
- Concept testing and prototyping reduced over 100 exhibits ideas to 16 final exhibits.

Edu, Inc. led a triage process using a Delphi Technique. Team members and external advisors independently scored proposed exhibits' likelihood of survival based on the complexity and relevance of the exhibit's main ideas and its interactivity. The ideas that received the best scores were ones that the audience would understand and find relevant. Only those ideas underwent further testing.

Exhibit concept-testing included using storyboards at the museum and in classrooms with focus groups and during interviews; and with the general public outside the museum and over the Internet.

The external advisory groups were useful in providing important feedback and perspective about cultural and gender issues.

2) How do people come to understand nano-science concepts and applications?

The summative study used pre- and post-visit interviews to compare guests' responses to six questions to explore whether *TSTS* increased visitors' knowledge of nanoscale-science and engineering content, their understanding of nanotechnology applications, and their interest in nanotechnology.

Exit interviews investigated what content or key messages visitors retained, what concepts they did not understand, and what more they wanted to learn about nanotechnology.

Edu, Inc. observed and interviewed explainers at Epcot and explored their role in increasing visitors' engagement.

What we found

The study discovered that the majority of visitors emerged from the exhibition with an increased interest in and understanding of nanotechnology. Visitors wanted to learn more about how nanotechnology might influence electronic gadgets, medical devices, and environmental sustainability.

Quantitative data and visitor comments clearly show that:

- The majority of visitors who, pre-visit, did not know something about nanoscale science demonstrated that the exhibition gave them new understanding of nanotechnology.

Nanobots and Other Misconceptions

Visitors shared chronic misconceptions . Many visitors misconstrued "nano" using terms like nanobot, nanochip, nano camera, iPod nano, nano pill, and "a nano".

FINDINGS: visitors got "nano"

Visitors showed increased interest in and understanding of nanoscale science. They wanted to learn more about nanotechnology applications.

- Visitors (both youth and adults) who already knew something about "nano" demonstrated that the exhibition reinforced or expanded that understanding.

Evaluation shows that formal learning goals and controlled vocabulary that repeated key ideas provided a strong organizing framework.

- Explainers and pre-teaching tools greatly increased visitors' engagement with the exhibits and their understanding of "nano."

Visitors thought smaller

Tracking the smallest thing people are thinking about may loosely indicate increased awareness of what they cannot see. Three questions from the summative study tracked the extent to which visitors showed increased knowledge of subvisible objects:

1. *What is the smallest thing you can see?*
2. *What is the smallest thing you can think of?*
3. *What is the smallest thing scientists can make?*

"See, think, and make" represent three response variables that may indicate a mental progression from considering macro or micro scale objects you can see, think of, or make towards mentioning nanoscale objects that cannot be seen.

Relative to their pre-visit responses to those questions:

- 40 percent of visitors revised the smallest thing they could see to something even smaller after using the exhibits.
- 74 percent of visitors (youth and adults equally) who named a macro or micro object as the smallest thing they could think of named a nanoscale object after using the exhibits.
- 81 percent of visitors who said macro or micro objects are the smallest thing scientists can make named a nanoscale object after using the exhibits.

Evaluators also noted how visitors used vocabulary from the exhibition:

- In post-visit interviews, 70 percent of visitors used "nano" vocabulary terms from the exhibition such as atom, molecule, carbon nanotube, nanometer, and nanotechnology.
- In post-visit interviews, 50 percent of visitors under age 18 mentioned "nano" vocabulary terms or main ideas from the exhibition.
- During short interviews, 90 percent of visitors recalled specific exhibits by name and pointed to exhibits where they saw nano-science content.

Visitors showed increased understanding and interest

Three questions from the summative study investigated increased awareness of, understanding of, or interest in nanoscale science content or nanotechnology:

THINKING SMALLER: content acquisition

In exit interviews visitors showed increased knowledge of subvisible objects. Seventy percent of visitors used "nano" vocabulary from the exhibition.

1. *What do you think this exhibition is about?*
2. *What do you think of when you hear the word "nanotechnology"?*
3. *How interested are you in learning about nanotechnology?*

- 50 percent of visitors said the exhibition was about nanotechnology in post-visit interviews compared to 10 percent in pre-visit interviews.
- 75 percent of visitors in exit interviews said when they hear the word nanotechnology they think about a nanotechnology application or main idea from the exhibition. Youth and adults both mentioned nanotechnology applications and ideas with the same frequency.
- 60 percent of visitors said they were more interested in learning about nanotechnology after using *Too Small to See* (compared to their pre-visit responses).

Visitors' qualitative comments show general movement towards increased understanding of and appreciation for nanotechnology. See Table 3.

GENDER	AGE	PRE	POST
F	8-13	Ipod	Carbon nanotubes
M	8-13	Really small things	Small particles that build together to make things
M	8-13	Little computer chips creating pictures	Molecules that create an object
M	8-13	Small technology	People using nanobits to make nanotubes, new things and computer chips
F	8-13	Ants	Phone stations – cancer treatment
F	8-13	Microscopic technology, wires and stuff	Nanometers, carbon nanotubes and how they're used to cure cancer
F	28-40	Small technology	How things are made that you cannot see
F	28-40	Really small things	The smallest particles that make up everything
M	41-55	Nanobots	Computer chips
M	41-55	Science	Making things
F	56-70	Really small things	This is the first time I heard of it (nanotechnology) – amazing things you can see
M	56-70	Small technology	Treating cancer with carbon nanotubes

MORE AWARENESS: increased understanding

In exit interviews half of visitors said *TSTS* was about nanotechnology, 75 percent mentioned a nanotechnology application from *TSTS*.

Visitors were more interested in and showed increased understanding of nanotechnology.

TABLE 3 What Do You Think of When You Hear the Word Nanotechnology? Sample responses selected from 150 interviews.

Learning goals and controlled vocabulary link to formal education

Formal learning goals provided a strong organizing framework for the exhibition and provided links to formal education standards.

The *TSTS* team developed four ideas or principles to guide the development process from formative to final build. These concepts focus on increasingly difficult nanoscale science and engineering content that the visitor would need to begin to better understand nanoscale and nanotechnology. These were:

- All things are made of atoms.
- At the nanometer scale, atoms are in constant motion.
- Molecules have size and shape.
- At the nanometer scale, molecules have unexpected properties.

The guiding principles were revised to the following formal learning goals:

- All matter is made of atoms
- Molecules are made of atoms and have structure.
- Atoms and molecules are always moving.
- Nanotechnology involves making things less than 100 nanometers in size.
- Scientists use nanotechnology to make computer chips, develop new medicines, and treat cancer.

Controlled vocabulary encouraged retention

To support its learning goals the team developed a controlled vocabulary of key words (e.g., atom, molecule, carbon nanotube, nanometer, nanotechnology). Because repetition builds retention, key words were intentionally repeated often across interpretive materials including exhibit labels, signs, multimedia kiosks, recorded audio messages at exhibits, and explainers' resources.

Exit interviews and mediated interviews showed that many visitors gained an increased awareness of "nano" by exposure to the key terms.

Explainers increased visitor engagement

Using explainers and pre-teaching new concepts greatly increased visitors' engagement with the exhibition and understanding of nano-science content and nanotechnology applications. Mediation was found to be extremely useful.

- At Epcot, the tracking study showed visitors who worked with explainers stayed at the exhibits longer and gave more detailed and insightful responses in exit interviews.
- When trained explainers engaged visitors and gave examples, those visitors demonstrated a greater understanding of nanoscale content in exit interviews.

LEARNING GOALS: links to formal education

Learning goals organized nanoscale-science content around main ideas. Repeating key vocabulary built retention.

EXPLAINERS: engaging visitors

Visitors who talked to explainers stayed at exhibits longer and showed greater understanding of nanotechnology in exit interviews.

Adult education for explainers

Explainers said that their training materials—including written materials, DVDs, and a presentation by the project PI—made them feel better informed and confident when engaging visitors.

Do other projects find similar benefit from using explainers? If so, this points to the need to develop train-the-trainer programs (for potential explainers) to help museum staff members and volunteers become comfortable and competent in helping visitors understand nanotechnology.

Pre-teaching main ideas

Pre-teaching—a technique from formal education—introduces the component vocabulary and concepts that constitute a more complex subject to increase the probability that the subject or skill will be understood.

To test the efficacy of pre-teaching on content acquisition, before using the exhibition 25 visitors read *What is Nanotechnology?*, a simple picture book (see Appendix IV) that explains "nano".

Tracking and exit interviews showed that visitors who read this picture book before they entered the exhibition showed a greater engagement with its content, spent more time in the exhibition, and showed more understanding of nanoscale content than did those who had not read the book. Further evaluation on other projects is needed.

3) What questions about nanotechnology do visitors want answered and what topics do they find most relevant?

During post-visit interviews evaluators posed two "meaningful questions" to explore what people understand and want to know about nanotechnology. (See sidebar and Appendix II.)

1. *What do you not understand about nanotechnology?*
2. *What do you want to learn about nanotechnology?*

What we found

The majority of visitors emerged from the exhibition with three questions:

- What is nanotechnology?
- What does it make (or, what are its applications)?
- How will it affect and improve our lives?

Visitors asked that nanotechnology applications relevant to their lives be presented, specifically:

- How does "nano" apply to computers and gadgets (youth)?
- How does "nano" apply to cancer treatments and medicine (adults)?

PRE-TEACHING: main ideas

Adult education is needed to train explainers.

25 visitors who were introduced to *TSTS* main concepts before using the exhibits showed greater engagement than visitors who did not read the picture book.

FIGURE 3 What Do You Not Understand About Nanotechnology? Post-visit responses.

EVALUATOR: *What do you not understand about nanotechnology? What don't you get?*

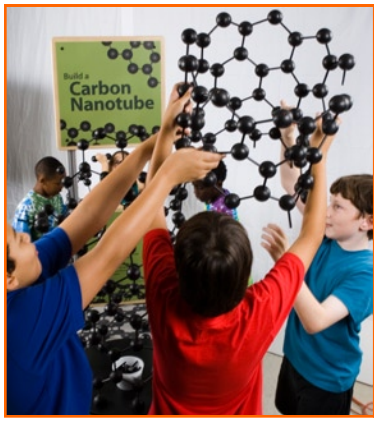
MALE (AGE 56-70): What can they build with carbon nanotubes? I learned that nanotubes are built from carbon atoms and you can't see them. But what's the application?

FEMALE (AGE 28 TO 40): If molecules are always moving and shaking why are things so sturdy?

FEMALE (AGE 14 TO 17): How do you build and where do you use a carbon nanotube?

FEMALE (AGE 14 TO 17): How do they use nano research to make medicines?

FEMALE (AGE 8 TO 13): Why do scientists have nano as a measurement?



- How is “nano” related to the environment, solar energy, and a sustainable future (youth and adults)?

4) What is the efficacy of models and other visualization tools to portray nanoscale objects, convey nano-science concepts, and explain nanotechnology applications?

Unobtrusive observation combined with mediated interviews, short interviews, a tracking study and sweeps, and interviews with explainers explored the role of models and visualization in increasing visitors’ knowledge and awareness of nanoscale science content and nanotechnology.

Models provide visual reference and long dwell times

“We told our [nine-year old] son he could do whatever he wanted at Epcot today and he wanted to build the carbon nanotubes again. We were here 90 minutes yesterday and have been here for 40 minutes so far today.”—A father from Ohio

Interactive models (e.g., exhibits such as *Build a Molecule, Build a Carbon Nanotube,* and *Carbon Nanotubes*) proved extremely popular and were mentioned by name in over 90 percent of short interviews and frequently in exit interviews.

Build a Molecule and *Build a Carbon Nanotube* showed consistently high use during sweeps and longer dwell times than other exhibits.

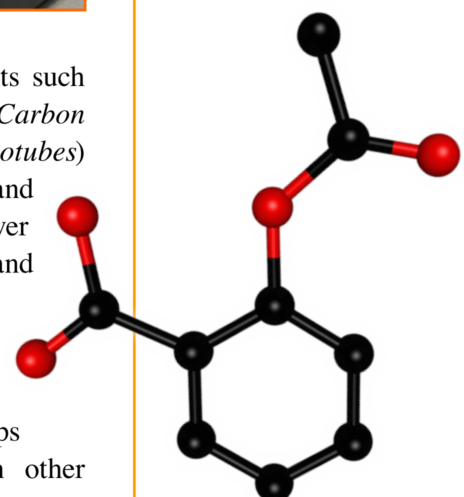
At *Build a Molecule* and *Build a Carbon Nanotube*, 80 percent (16 of 20) of explainers reported overhearing conversations about science and molecules among and between visitors. Evaluators observed the same.

Visitors recognized ball-and-stick models of atoms and molecules.

Over the course of four days at Epcot evaluators observed visitors returning later in the day or the following day to revisit model and visualization exhibits.

Interactive models

Visitors used *Build a Molecule* and *Build a Carbon Nanotube* longer than other exhibits. *Carbon Nanotubes* provided a larger-than-life example of a carbon nanotube frequently referred to in exit interviews.



Visitors recognized ball-and-stick models

Of three options, the ball-and-stick model was the most recognized in formative evaluation. Children and adults compared large graphic images and physical models representing molecules—ball-and-stick, ball-and-spring, and space-filling. People said they had seen ball-and-stick in school.

Computerized visualizations popular and effective

Enabling visitors to view familiar objects at macro-, micro-, and nanoscopic magnifications proved popular.

"The Zooming into Nano *[exhibit] was the first time I've ever seen what something common—like a butterfly wing—looks like really close up. I was there 20 minutes and did it with my daughter. My kids finally had to drag me away."* –A mother from Virginia

"The Magnification Station *let me see what things look like really, really, really, small. I mean, if scientists took those pictures that means it's real."* –Girl, age 8 to 13

Computerized visualization exhibits that let visitors see, zoom, and compare images at the macro, micro, and nano scales were the most used exhibits.

96 percent of visitors used *Zoom into Nano* and *Magnification Station* was the second most used.

(5) How effective are interpretive media in communicating nanoscale-science concepts and nanotechnology applications?

Evaluation investigated the role of signs and media in communicating nanoscale science and nanotechnology. Methodology included unobtrusive observation of visitors using signs followed by short interviews, the tracking study, and detailed observation of and interviews with 50 people using the multimedia kiosk.

Visitors read labels and quick-read signs with basic information

Clear, short, and "instant read" exhibit titles proved important to orient visitors to the exhibitions' key vocabulary terms (based on evidence from short interviews).

At Epcot, where title signs for *Build a Molecule* and *Build a Carbon Nanotube* were prominent, 20 percent of people initially thought the exhibition was about molecules or carbon

INTERPRETATION: signs and multimedia

Many visitors read exhibit titles and short "basic" signs. 70 percent of visitors observed used multimedia kiosks – almost all for 30 seconds or less.

FIGURE 4 Viewing familiar objects at macro, micro, and nanoscopic magnifications proved popular.

FIGURE 5 Audience testing led to three sign types: titles, basic (less than 25 words), and “textbook” (three paragraphs for readers with a background in science or those who wanted more information.).

nanotubes (as revealed in pre-visit interviews).

Forty percent of youth observed—especially girls age 10 and up—were seen reading or skimming basic signs. Often reading would be very quick—under ten seconds—but five of six girls between age 10 and 12 who glanced at signs for ten seconds or less correctly explained the signs’ meaning to evaluators.

Explanatory, text-rich “textbook” signs were used least frequently but for long periods of time. Most visitors observed glanced at or ignored textbook signs. Out of 50 observations of textbook-sign-readers, only five people—all adult men over age 40—read the signs in their entirety.

Multimedia kiosks and large format projection used frequently

- Multimedia kiosks were popular—especially with youth—and were used by over 70 percent of visitors observed.
- Audio-and-video kiosks were used more frequently than those with audio only.
- Average dwell time at kiosks was 30 seconds. Messages were 90 seconds—too long for most visitors.
- Adults over age 40 were the only visitors who listened to entire 90-second messages.
- Youth requested fast, upbeat messages.
- Spanish-speaking adult visitors requested media available in Spanish.
- Large-scale projection attracted visitors’ attention and was mentioned frequently in interviews. Over half of visitors observed large-scale projection of common objects zooming into the nanoscale.

Listen to a Nano Story coffee table

Benches situated next to *Listen to a Nano Story* were extremely popular with parents and grandparents who listened to multiple stories while watching children.

Visitors said they want a menu on the exhibit that lets them interrupt one story and choose another.

Also, when benches are placed so visitors can see the large scale projection they watch the projection.

6) To what extent is the exhibition accessible to underserved audiences—those with disabilities, ethnic minority communities, and girls?

Understanding that audience diversity is a central tenet of NSF-sponsored programs, evaluators paid special attention to the exhibition's success in engaging ethnic minority communities, persons with disabilities, and girls.

Accessibility

The *Too Small to See* team enthusiastically supported the need for universal accessibility and made a concerted and largely successful effort to make the exhibition accessible to all visitors.

External evaluators worked with visitors with disabilities to test exhibit prototypes' accessibility and safety for people with mobility and coordination-related disabilities and those who are blind or deaf. Disability advisors included two blind people, a person with low vision, two deaf teenagers and a deaf adult, an adult with severe coordination issues, and two people in wheelchairs. Evaluators further tested exhibit accessibility at Epcot for those with mobility, coordination, and hearing disabilities.

What we found

Using the Smithsonian Institution's Exhibition Accessibility Checklist as a guide, evaluators made the following observations.

Too Small to See provides appropriate accessibility from visitors' seated positions, an accessible circulation route, and clear pathways for wheelchairs (as *TSTS* was set up at Epcot and Sciencenter).

Exhibit controls are physically and visually accessible to those visitors seated, those with reduced coordination, those using most assistive devices, and those with low vision.

Build a Molecule, Build a Carbon Nanotube, and *Carbon Nanotubes* are highly tactile; those exhibits' activities are accessible to blind and low-vision users.

Listen to a Nano Story and audio from the multimedia kiosks are accessible to visitors who are blind. The remaining exhibits—all based on magnification and visualization—are not accessible to users who are blind. The team faced a paradox because *Too Small to See* exhibits based on visualization are central to the exhibition's education strategy for its seeing visitors, but are not accessible to visitors with no or very poor vision.

Signs and audio media are not universally accessible.

- The exhibits—with the exception of *Infinity Crystal* and *Carbon Nanotubes*—do not provide audio labeling.
- Dense copy on textbook signs is not accessible to low-vision users or to people who have difficulty reading English.

Multimedia kiosks were popular, but messages were too long for kids.

Over 70 percent of visitors used multimedia kiosks. Multimedia kiosks with audio and video were the most popular.

Youth asked for a menu of selections 20 seconds in length that are "cool enough for kids." They wanted professionally developed media "more like TV except you get to choose."

ACCESSIBILITY:
generally accessible

TSTS is accessible for people in wheelchairs and those with reduced coordination.

Visualization exhibits are not accessible to people who are blind. Multimedia kiosks lack captioning or sign interpretation and are not accessible to deaf people.

- All exhibits—with the exception of the multimedia kiosks' audio components—are accessible to visitors who are hearing-impaired.
- In their present state, the four video kiosks lack open captioning and are not in compliance with captioning as required under Section 1194.24(c) of the Section 508 standards of the Rehabilitation Act (ADA). A verbatim script is posted near each video monitor.

Diversity

The *Too Small to See* team made a significant effort to include underserved-community representatives as advisors, as explained above. The team earmarked funds to ensure that underserved audiences could experience some version of the exhibit (as explained below). Edu, Inc. provided web-based testing of signs and media with a diverse national audience.

Of those visitors interviewed during the summative study, 23 percent were non-Caucasian. No significant differences were observed in responses to interviews.

Team members tested, but chose not to supply, Spanish-language signs for *TSTS*. Beyond the scope of the funded proposal, the project leaders and designers developed a second, smaller (1,500 square foot) exhibition comprising exhibits and media with bilingual signs (Spanish/English).

The project funded the second exhibition's installation in the University of California, Santa Barbara (UCSB), where school groups from underserved ethnic or cultural minority communities will visit. Dr. Evelyn Hu of UCSB commented "it's wonderful the exhibits are in Spanish."

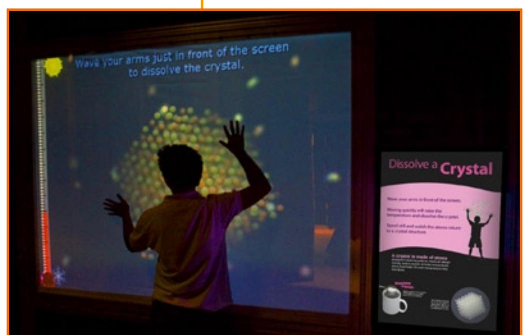
The project is seeking supplemental funding to install the second exhibition *(TSTS-2)* at museums serving underrepresented populations but without resources to rent the exhibition. Supplemental funding will allow placing *TSTS-2* in museums at little or no cost to the host museum. Based on the evidence of the primary exhibition's success, appropriate additional funding is recommended.

7) What is the sustained impact of *Too Small to See* in the absence of NSF funding?

The sustained impact of *Too Small to See* in the absence of long-term NSF funding is positive. The possibility of installing a 1,500-square-foot permanent exhibition at Disney's Epcot is being negotiated. At the time of publication these arrangements were not final, but represent an opportunity private business would envy–exposure to over one million diverse visitors per year. The Sciencenter reports it has signed lease

DIVERSITY: TSTS-2

With current funds the team built a second, smaller exhibit – *TSTS-2* – to reach underserved audiences.



Icon-based signs helped to direct nonreaders.

Evaluators observed visitors intuitively understanding icon-based signs – an effective strategy for people who do not read English.

agreements with four museums. The exhibition is currently booked between now and the summer of 2009.

8) Is the exhibition safe, durable, and marketable as a traveling exhibition?

Each exhibit was subjected to a safety inspection based on guidelines developed by the United States Consumer Product Safety Commission. Exhibits appear to be free of obvious hazards, pinch points, and entrapment hazards, and seem generally in keeping with consumer product safety standards and guidelines provided by the Public Safety Playground Handbook.

The Sciencenter in Ithaca, NY, appears fully prepared to provide high quality and reliable management of the logistics and technical support required for this traveling exhibition. The Sciencenter has successfully developed, shipped, and installed five NSF-ISE funded exhibitions since 1999.

During a September 2007 site visit the Sciencenter provided evaluators with evidence of plans to send a person to the exhibition's out-of-town venues to help with set-up. Sciencenter possesses duplicates of key components that can be shipped from the Sciencenter by overnight courier to effect necessary repairs. The Sciencenter appears equipped to provide a high level of technical support to ensure the exhibition withstands demanding museum environments.

TRAVELLING EXHIBITION: durable; safe; supported

TSTS appears durable and in keeping with consumer product safety standards. Sciencenter is experienced managing logistics and in providing technical support for traveling exhibitions.

THE FOLLOWING SECTION SUMMARIZES the exhibition's impact and presents evidence to support findings and recommendations presented in the "What Was Learned" section. Mixed methods—a balanced blend of quantitative and qualitative data—measured the project's effects and the extent to which its goals were attained. Descriptive and telling visitor comments are combined with simple tabular data.

Impact One: Research and Publication on Nano Literacy

The front-end research for *Too Small to See* sponsored formal educational studies on children and adults' conception of subvisible size and scale.[1] The study established that there is a low public understanding of nanoscale science content and nanotechnology. Following publication of research findings in a peer-reviewed journal, the authors have received unsolicited requests for further information on their findings from education researchers. The strategic impact of this article is yet to be determined. Three others cited the 2006 research (per Google Scholar and Scopus). Additional publications resulting from these studies are in preparation.

Impact Two: Number Served

An estimated one million visitors toured *TSTS* during its six-months at Epcot. *TSTS* is expected to reach an additional two million visitors during its national tour. The exhibition is currently booked through May 2009 at four museums.

Impact Three: Evidence Indicating Increased Awareness of Nanotechnology

Evidence shows increased awareness of nanotechnology across a balanced and diverse audience sample.

The intended audience for *TSTS* is an ethnically diverse mix of youth age eight to 13, other teens, and adults. The *TSTS* study sample represents a fair and reasonable split by age, gender, and ethnicity. Fifty-four percent of the test audience is under age 18; 39 percent of the audience is age eight to 13. Gender for age 8 to 13 and for adults are both split 53 percent female and 47 percent male. Twenty-one percent of the sample was non-Caucasian.

IMPACT: research; numbers served

Peer-reviewed publication of front-end research documents low public understanding of nanotechnology.

An estimated three million people will visit *TSTS*.

Evaluation shows an increased awareness of nanotechnology across a diverse sample of youth and adults.

TABLE 4 Gender: Audience Sample for Summative Report Pre-Post Study

COUNT		GENDER				TOTAL	PERCENT
		FEMALE		MALE			
AGE	8-13	31	21%	27	18%	58	39%
	14-17	16	64%	9	36%	25	17%
	18-27	5	36%	9	64%	14	9%
	28-40	14	58%	10	42%	24	16%
	41-55	11	65%	6	35%	17	11%
	56-70	6	50%	6	50%	12	8%
TOTAL		**117**	**78%**	**33**	**22%**	**150**	**100%**

TABLE 5 Ethnicity: Audience Sample for Summative Report Pre-Post Study

COUNT		ETHNICITY				TOTAL
		CAUCASIAN		NON-CAUCASIAN		
AGE	8-13	45	78%	13	22%	58
	14-17	21	84%	4	16%	25
	18-27	12	86%	2	14%	14
	28-40	14	58%	10	42%	24
	41-55	13	76%	4	24%	17
	56-70	12	100%	0	0%	12
TOTAL		**117**	**78%**	**33**	**22%**	**150**

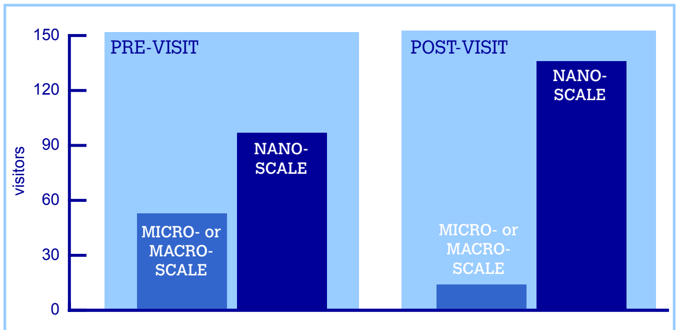
Visitors showed increased awareness of and interest in nanotechnology

Simple counts offer evidence of visitors' awareness of the smallest thing they could think of, moving from mentioning macro- and micro-scale objects in pre-visit interviews to nano-scale objects in post-visit interviews.

TABLE 6 Pre- and Post-Visit Responses to "What is the Smallest Thing You Can See?"

What is the smallest thing you can see?				
60 of 150 visitors named a smaller-scale object post-visit				
	Macro	Micro	Nano	**Total**
Pre-Visit Scale Mentioned	123	14	13	**150**
Post-Visit Scale Mentioned	93	14	43	**150**
Smaller Post-Visit Scale	30	0	30	**60**
Total Smaller	**60**			
Percent Smaller	**40%**			

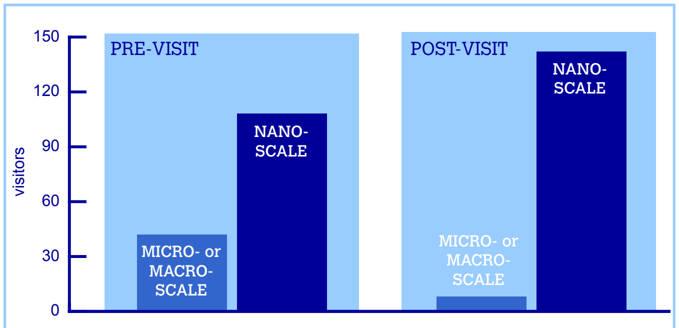
What is the smallest thing you can think of?



74 percent of visitors (39 of 53) who named a macro or micro scale object pre-visit named a nano object post-visit.

FIGURE 6 Pre- and Post-Visit Responses to "What is the Smallest Thing You Can Think of?"

What is the smallest thing you think a scientist can make?



81 percent of visitors (34 of 50) who named a macro or micro object pre-visit named a nano object post-visit.

FIGURE 7 Pre- and Post-Visit Responses to "What is the Smallest Thing Scientists Can Make?"

FIGURE 8 Visitors show increased awareness of and interest in nanotechnology.

Visitors' comments after using TSTS show increased awareness of and interest in nanotechnology

"Nanotechnology is small particles that build together to make things." *Boy, age 8–13*

"Nanotechnology is scientists making something out of something very, very small." *Girl, age 8–13*

"I think nanotechnology is about seeing things that you can't see with your eyes." *Boy, age 8–13*

"I wonder what things really look like at the nano level." *Girl, age 8–13*

"Is there anything smaller?" *Male, age 18–27*

"What I thought was that nanotechnology was about microcomputers. What I learned was that biologists, chemists, and engineers work together to build nanotechnology." *Male, age 28–40*

"Nanotechnology means developing the skills for working with incredibly small parts." *Female, age 56–70*

"I think about treating cancer with carbon nanotubes." *Male, age 56–70*

"Nanotechnology is a new high technology. The edge of science." *Male, age 56–70*

Impact Four: Models and Visualization— a Proof of Concept

Visitors used models longest and visualization most often

A tracking study and sweeps showed that, in general, hands-on models were used longer than other exhibits and visualization exhibits were used the most often.

A tracking and timing study documents what exhibits a visitor uses and for how long they use it (dwell time). Sweeps count the number of people at an exhibit. Evaluators tracked 75 visitors and conducted 10 sweeps during peak hours over two days.

Relative to typical science-museum visits, *TSTS* visitors spent longer than average time in the *TSTS* exhibition, spent considerably longer than average at models, and used visualization exhibits most frequently. The average time in the *TSTS* exhibition was 16 minutes; 19 percent of visitors stayed more than 30 minutes. Estimates of average time in an exhibition at a science museum range from eight to 15 minutes.[6,7]

The hands-on model exhibits *Build a Molecule* and *Build a Carbon Nanotube* had the longest average dwell time (eight and half minutes and six and a half minutes, respectively). Evaluators observed visitors leaving the exhibition and returning later in the day to use *Build a Molecule* and *Build a Carbon Nanotube* again.

IMPACT: models and visualization

Visitors were engaged by models of enlarged atoms, molecules, and nanoscale objects and interactive visualization. Visitors used these exhibits longer and more frequently than other exhibits.

Visitors using hands-on models had animated conversations, did experimentation and testing, and collaborated with family members and other visitors—all evidence of inquiry.

- At *Build a Molecule* and *Build a Carbon Nanotube*, 80% (16 of 20) of explainers reported conversations about science and molecules among and between visitors.
- Conversations included parents teaching children, children talking to each other, grandparents teaching their grandchildren and other peoples' children, and older siblings explaining a concept to a younger child or a parent.
- An explainer said "It forces people to work together. Even strangers work with each other." Evaluators observed the same.

FIGURE 9 Evidence of Inquiry—*Build a Molecule* and *Build a Carbon Nanotube*

	Exhibits Ranked by Use	# OF USERS (OUT OF 75)	% OF VISITORS WHO USED	AVERAGE TIME AT EXHIBIT	SHORTEST TIME AT EXHIBIT	LONGEST TIME AT EXHIBIT
1	Zoom into Nano	72	96%	03:08	00:06	14:57
2	Portages: Multimedia Kiosks	54	72%	00:23	00:04	01:30
3	Build a Molecule	45	60%	08:29	00:15	48:02
4	Infinity Crystal	36	48%	00:22	00:04	03:12
5	Magnification Station	32	43%	02:38	00:07	14:41
6	Listen to a Nano Story	32	43%	00:31	00:08	01:30
7	Atom Transporter	31	41%	04:20	00:21	18:00
8	Build a Carbon Nanotube	26	35%	06:26	00:15	48:02
9	Stretch a Molecule	15	20%	00:41	00:10	01:10
10	Carbon Nanotubes	15	20%	00:14	00:02	00:40
11	Photolithography	13	17%	02:24	00:07	07:40
12	Small, Smaller, Nano	13	17%	01:10	00:19	03:02
13	Salt Dissolve	13	17%	00:49	00:10	01:45
14	Intro Panel	5	7%	01:15	00:24	02:30

TABLE 7 Tracking Study – How many people used exhibits? Exhibits ranked by number of tracked visitors that used the exhibit.

Exhibits Ranked by Longest Average Use	AVERAGE USE
More Than Two Minutes	
Build a Molecule	08:29
Build a Carbon Nanotube	06:26
Atom Transporter	04:20
Zoom into Nano	03:08
Magnification Station	02:38
Photolithography	02:24
Less Than Two Minutes	
Intro Panel	01:15
Small, Smaller, Nano	01:10
Salt Dissolve	00:49
Stretch a Molecule	00:41
Listen to a Nano Story	00:31
Infinity Crystal	00:22
Carbon Nanotubes	00:14

TABLE 8 Tracking Study – How long did people use exhibits? Exhibits ranked by average use.

Sweeps

RANK	EXHIBIT NAME	NUMBER	PERCENT
1	Zoom into Nano	70	16%
2	Magnification Station	60	14%
3	Build a Molecule	59	14%
4	Build a Carbon Nanotube	55	13%
5	Infinity Crystal	33	8%
7	Salt Dissolve	26	6%
8	Atom Transporter	26	6%
9	Stretch a Molecule	11	3%
10	Intro Panel	10	2%
11	Carbon Nanotubes	8	2%
12	Listen to a Nano Story	7	2%
		433	**100%**

Note: Sweeps conducted at Epcot due to its large crowds. Photolithography and Particle Progression (Small, Smaller, Nano) were not on display at Epcot.

TABLE 9 Sweeps – How many people used what exhibits?

Visualization exhibits were used frequently. *Zoom into Nano* was used by 96 percent of visitors for over three minutes on average. *Infinity Crystal* and *Magnification Station* were used by over 40 percent of visitors. Evaluators noted visitors returning to use visualization exhibits multiple times during their visit.

Impact Five: Collaboration

Collaboration evolved between formal and informal education

Significant collaboration occurred within the *TSTS* project.

Too Small to See was an intentional collaboration among Cornell University scientists, Sciencenter, of Ithaca, NY, and Painted Universe, Inc., an independent exhibit design firm. The importance of the collaboration was bringing a variety of perspectives, knowledge, skill sets, and professional networks to bear on the project.

University scientists provided access to leading-edge technology, content expertise, and a wide range of professional resources such as *Earth and Sky* radio spots and web content. The science museum brought understanding of informal science education and a dedication to providing a positive visitor experience. The design firm brought creativity, enthusiasm, and long experience.

The Sciencenter developed educational program materials to support museum-educators and teachers using the exhibition.

Materials were developed in collaboration with Cornell University and NISE Net members from other museums and research institutions.

Additional collaborators included: Emily Maletz Graphic Design, Tamarack Design Inc., Mine-Control, Earth & Sky, and Technofrolics. Imagery was provided by many sources including Dennis Kunkel, David Goodsell, and IBM in addition to the project team.

External Advisory Board members, who were extremely helpful in the early stages of the project include:

Dennis Bartel (Exploratorium, formerly with TERC), David Haase (North Carolina State University), Evelyn Hu (UCSB, California NanoSystems Institute, Betsy Fleischer (Materials Research Society), J. Shipley Newlin (Science Museum of Minnesota), and Mark Flowers (Nanoscience Instruments)

IMPACT:
collaboration

TSTS benefited from significant collaboration between formal and informal science education. Sciencenter is collaborating with NISE Network.

Exhibition Flyer—About the Exhibition and Exhibits

Exhibition for Rent

Sciencenter
601 First Street
Ithaca, NY 14850
607-272-0600
607-277-7469 (fax)
www.sciencenterexhibits.org
rentals@sciencenter.org

Too Small to See

Zoom into Nanotechnology

Find out how scientists see and make things that are too small to see. Nanoscale science and engineering is the process through which materials are manipulated on the molecular scale to generate very, very small structures and devices.

Designed for 8-13 year olds and their families.
www.toosmalltosee.org

Partners: Cornell University, Painted Universe, Inc.;

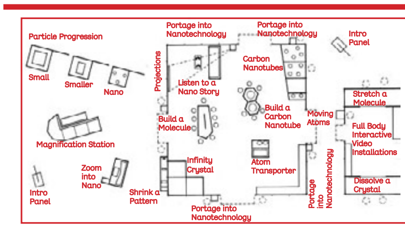
Funded by NSF

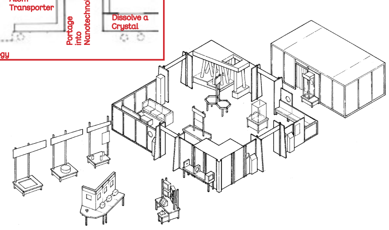
Rental Fee: $85,000/3 months

Size: 5,000 sq.ft.
9.5 foot ceiling minimum

Shipping: fits in 2 semi-trailers
renter pays inbound shipping

Rental managed by Sciencenter





Key Concepts

- All things are made of atoms
- Atoms bond together to form molecules
- Atoms and molecules are always moving
- There are one billion nanometers in a meter
- Nanotechnology is: making new materials and tiny devices smaller than 100 nanometers in size
- Nanotechnology allows scientists to make new things like: smaller, faster computer chips and new medicines for diseases such as cancer

Photo credits:
courtesy of Sciencenter;
Gary Hodges - www.jonreis.com

Painted Universe Inc.

October 2007

Too Small to See Exhibit Descriptions

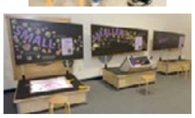
Small, Smaller, Nano

In this exhibit cluster, visitors are oriented to three size scales: small (greater than 100 micrometers), smaller (1 to 100 micrometers), and nano (less than 100 nanometers).
There are a billion nanometers in a meter!


Entry Panels (3)
Watch a video introducing key exhibition concepts. Two additional panels without audiovisuals are provided for use in lobbies or at other entries.

Magnification Station
View three different magnifications of familiar objects (such as a butterfly wing, an oyster shell and a salt crystal) to see that all matter is made of atoms.

Zoom into Nano
Turn a wheel to zoom in and out from the macroscopic to the nanoscopic world and back again. Go at your own speed to explore four fascinating objects.




Particle Progression
Use your senses to lead you on a nano journey from
- **small (sand)**

to
- **smaller (dust)**

to
- **nano (smell)**.

Discover that molecules are too small to see but not too small to smell.

Making Nano Structures

These two exhibits show different ways to make very, very tiny structures and devices: moving lots of atoms at once (Shrink a Pattern) and moving atoms one-by-one (Atom Transporter).

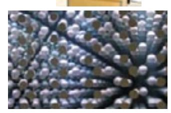
Shrink a Pattern
Design patterns of translucent colored cubes and then use light and lenses to shrink the pattern many times.

Atom Transporter
Experience the challenge of arranging individual atoms into a pattern while the atoms are in motion.

Seeing Nano Structures

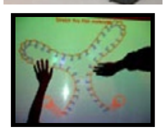
Within this courtyard of exhibits, models of atoms and molecules are enlarged to 100 million times their actual size. Visitors can view, build, and stretch molecules while exploring their shape and structure. Visitors experience the constant motion of atoms and molecules.

Shaking Solids
See that atoms and molecules are always moving - even in solid objects.

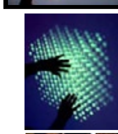


Infinity Crystal
Immerse yourself in a crystal's repeating patterns of atoms that seem to go on forever.

Carbon Nanotubes
Climb and play among the carbon nanotubes while learning about their potential uses.



Stretch a Molecule
Use your hands to grab and pull apart the ends of a virtual RNA molecule. When you let go, the molecule folds back up into its favorite shape.
(Full Body Interactive Video Installation)



Dissolve a Crystal
Dissolve a virtual crystal of salt using your body's movement to generate heat.
(Full Body Interactive Video Installation)

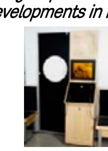
Build a Molecule
Have fun creating your own molecular models against a background of compelling imagery showing the beauty and complexity of the molecular world.

Build a Carbon Nanotube
How high can you go? Work in a group to build up gigantic carbon nanotube models.

Banners and Video Projections
Enhance and expand vertical spaces.

Nano and Me

This group of exhibits highlights the implications of current and future developments in nanoscale science and engineering.



Portages into Nanotechnology (4)
At four video kiosks, learn how scientists are using nanotechnology to develop new tools and materials that may affect our lives.

Listen to a Nano Story (2)
Sit back and listen to stories about nanotechnology from the popular *Earth and Sky* radio series at two coffeetable stations.

Meaningful Questions Investigate Inquiry

The use of "meaningful questions" is presented as a methodology for evaluators in the ISE field to consider. The technique asks people what they do not know to probe what they do understand.

"Meaningful questions" is a technique designed to assess inquiry in science education, especially with young children who do not respond well to interviews but often show their mental processes through questioning (Kudlea, 2001).[8]

It is useful in formative and summative evaluation as a means to start a conversation that encourages visitors to talk about what they saw, what they did (which exhibits or media they used), and what they did not understand.

Just as skilled teachers and professors pose meaningful questions to engage learners in inquiry-based learning—in post-visit interviews evaluators used two inquiry-based interview questions to help visitors think about what they experienced at *TSTS*.

TABLE 7 Meaningful Questions

GENDER	AGE	WHAT DO YOU NOT UNDERSTAND ABOUT NANOTECHNOLOGY?	WHAT DO YOU WANT TO LEARN ABOUT NANOTECHNOLOGY?
M	8-13	Why is it small? Why do we want to work with small things?	Are there more small things to find?
F	8-13	I didn't understand how scientists make the carbon nanotubes.	How do you build nano things?
F	8-13	Why do we have nanotechnology?	Why do we use it?
F	8-13	What does it mean?	Why do scientists have nano as a measurement?
M	8-13	How do they do it? Why?	Everything I can.
F	14-17	What is it?	How do they use it?
F	14-17	Where do you use a carbon nanotube?	How do you build nanotubes?
F	14-17	The idea of nano size.	How do they decide how to make medicine?
M	14-17	How does it work? What tools? What is the process?	What is it being used for right now?
F	14-17	How do they do it?	How do you take something small like molecules and make it into something big, like wires we'd use?
F	28-40	Where do they get the molecules?	
F	28-40	How do they do it? How did it come to be? What's the history?	What are other countries doing compared to the US?
M	41-55	How do they make it? Where is it made?	First thing I want to know is applications.
F	41-55	How did this come about? How is it used?	I'm looking for information to make me think about it.
M	41-55	How do they see the atoms?	Where do they get the molecules?
M	41-55	Manufacturing techniques—how do you move and manipulate it?	Now I know it's not conceptual, you can actually see it.
M	56-70	Why does somebody try to build a nanomagnet?	What would they do with it?
M	56-70	What can they build with nanotubes? I learned they are built from carbon atoms and you can't see them.	What's the application?

Pre-Post Interview Protocol

Too Small to See Entry and Exit Interviews

Purpose: Establish the guest's awareness, understanding and interest in nanotechnology before and after using the exhibition; and document the guest's perception of what the exhibition was about.

Method: Evaluators will ask 100 adult visitors and 100 family visitors entry and exit interview questions. Entry interviews take two minutes. Exit interviews take three minutes.

ID: 101 Gender: M / F Ethnicity: Caucasian / Non-Caucasian Age: <8 8-13 14-17 18-27 28-40 41-55 56-70 70+

Entry Interview

1. What is the smallest thing you can see?
2. What is the smallest thing you can think of?
3. What do you think is the smallest thing that scientists can make?
4. What do you think this exhibition is about?
5. What do you think of when you hear the word 'nanotechnology'?
6. How interested are you in learning about nanotechnology?

(1) No interest; (2) Some Interest; (3) Interested; (4) Very Interested; (5) Extremely Interested

Exit Interview

1. What is the smallest thing you can see?
2. What is the smallest thing you can think of?
3. What is the smallest thing that scientists can make?
4. What was the exhibition about? (Probe: Did you see anything about nano or nanotechnology? What?)
5. What do you think of when you hear the word 'nanotechnology'?
6. How interested are you in learning more about nanotechnology?

(1) No interest; (2) Some Interest; (3) Interested; (4) Very Interested; (5) Extremely Interested

7. What do you not understand about nanotechnology?
8. What do you want to learn about nanotechnology?

Pre-teaching Main Ideas

A picture book *What is Nanotechnology* exposed 25 visitors to the exhibition's main ideas before they used the exhibits. Below are comments from post-visit interviews with visitors who read the book.

"The book engaged me. It got me thinking about computers and that something new could be stronger than steel." *Female, age 56–70*

"It was helpful. If nothing else, taking three minutes to go through grabbed my attention so I wanted to learn more." *Male, age 28–40*

"The book made the exhibits more understandable." *Female, age 18–27*

"It [the book] helped. I understood what I was seeing." *Female, age 18–27*

"The book was simple. It gave me the main idea so I would know what to look for." *Female, age 28–40*

"The book made me think about the relative size of objects. It made me think there are actual, real objects that exist but you can't see them." *Male, age 56–70*

"Reading the book made me realize how cool this exhibit was. After reading the book I wanted to spend time here. I got a lot more out of it because you showed me the book first. Where can I get more info? Is there a website?" *Female, age 41–55*

"When I first saw these exhibits I would have walked by. After taking a few minutes to do the book I wanted to learn more. I spent 20 minutes here because now I'm curious and want to learn more." *Female, age 41–55*

(A mother sought out the evaluator and shook the evaluator's hand) "Thank you so much for doing this book with my family. It made it so much clearer. My teenage daughter was totally engaged and talking to me and showing me the exhibits." *Female, age 41–55*

FIGURE 10 Pre-teaching Picture Book (below and pages 32–35)

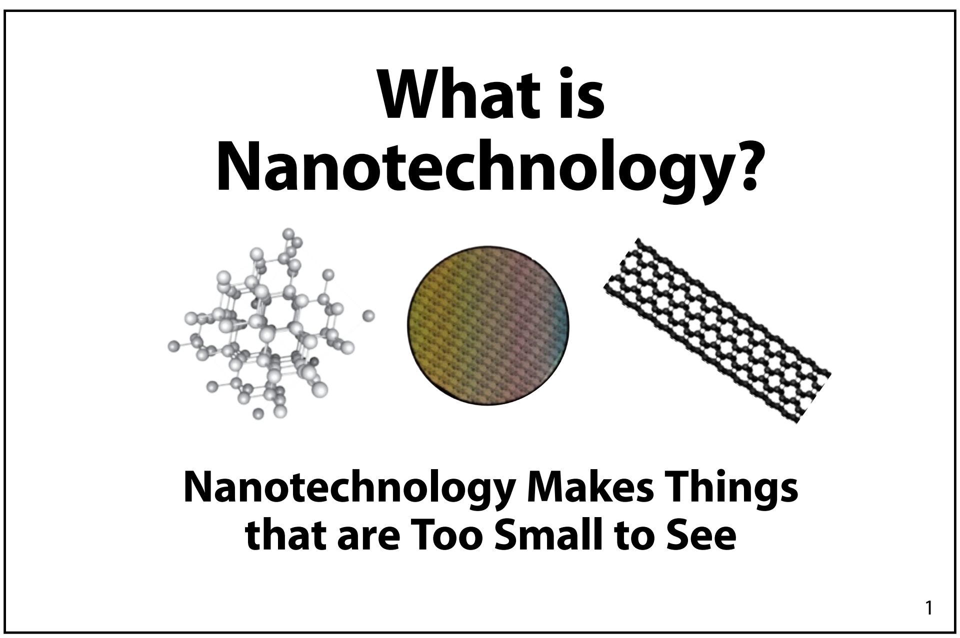


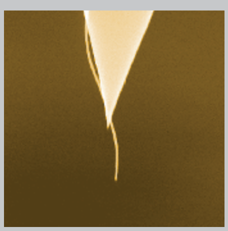
FIGURE 10 (continued)

Think of something too small to see?

2

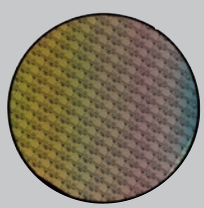
Nanotechnology makes things the size of atoms and molecules.

Carbon nanotube



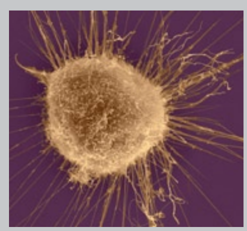
A new material that is stronger than steel

Computer chip



Nano wires help computer chips work faster

Cancer cell



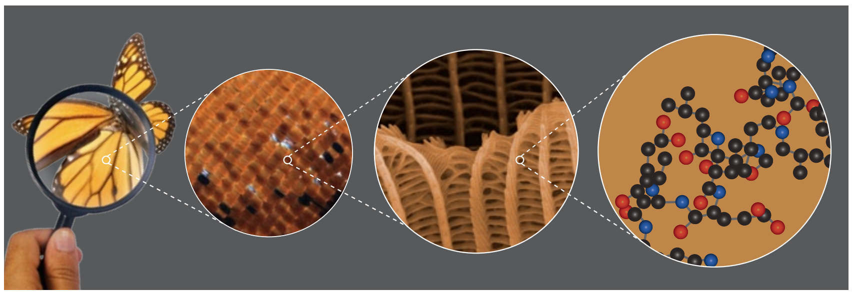
Nano medicines can be used to treat cancer

Scientists use nanotechnology to develop new materials, make computer chips, and treat cancer.

3

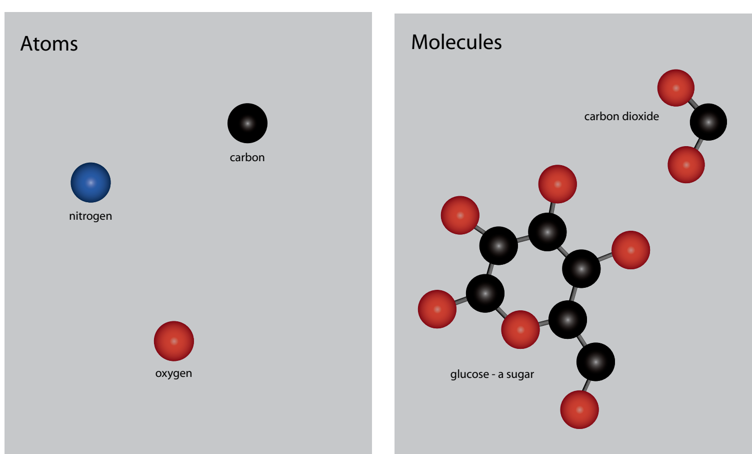
FIGURE 10 (continued)

All things are made of atoms.



4

Atoms bond to make molecules.

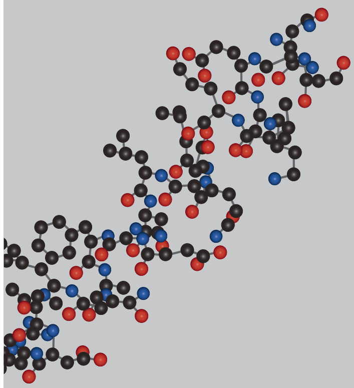


5

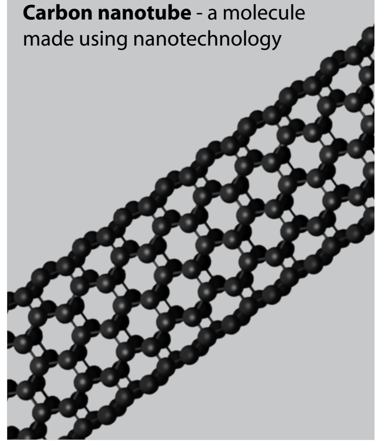
FIGURE 10 (continued)

Molecules have size and shape.

Keratin - a molecule in hair and skin



Carbon nanotube - a molecule made using nanotechnology

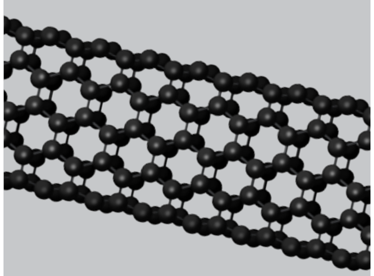


You can't see molecules but they are real.
Different kinds of molecules are different sizes and shapes.

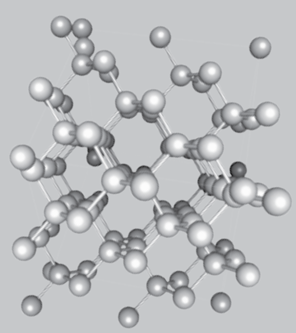
6

Nanotechnology makes things by connecting molecules.

Carbon nanotube - a molecule made using nanotechnology



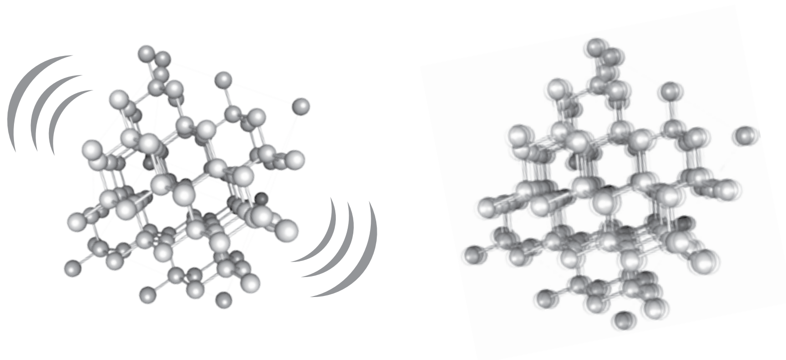
Silicon Crystal - a molecule in a computer chip



7

FIGURE 10 (continued)

Molecules are always moving.



It is hard to connect molecules using nanotechnology because they are always moving.

8

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About the Evaluators

Tina Phillips

Tina Phillips leads several citizen-science projects at the Cornell University Lab of Ornithology. She is conducting doctoral research in Science Education at Cornell University, examining learning outcomes of different models of citizen science. Tina recently traveled to China as part of an NSF-sponsored delegation examining China's informal science education.

Douglas Spencer

Douglas Spencer is a founding principle of Edu, Inc. which is an outgrowth of his doctoral research in Education at Cornell University. Dr. Spencer has led over fifty evaluation projects since 1993. Clients include Cornell and Harvard Universities, The University of California, NASA, The National Science Foundation, The US Department of Education, PBS, and private foundations.

Victoria Angelotti

Tori Angelotti is an education evaluator and a teacher with nine years of classroom experience teaching elementary science in an ethnically diverse school in South Florida where she was named Teacher of the Year. She has worked with Edu, Inc. since 2000. Her expertise is translating difficult science content to a level that middle-elementary children can understand.

Shane Murphy

Shane Murphy is a mathematics teacher with 15 years of experience – three years in middle-elementary and 12 years in high school classrooms. Shane was instrumental in conducting front-end research and formative evaluation for Too Small to See. She completed her graduate studies in mathematics education as an NSF-scholar at the State University of New York.

About Edu, Inc.

Edu, Inc. (eduinc.org) evaluates education, training, and e-Learning for universities, foundations, businesses and museums. A full-service education research and evaluation firm, Edu, Inc. offers feasibility studies, market research, front-end research, and formative and summative evaluation.

Incorporated in 1993, Edu, Inc. serves a select portfolio of clients. The company operates from Ithaca, New York and Fort Myers, Florida.