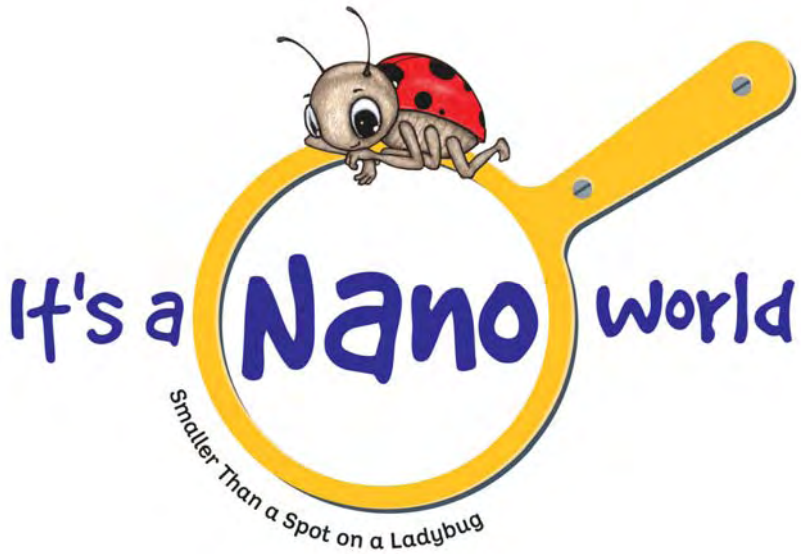

A Study of Use

Findings from a Summative Study

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Executive Summary

Abstract

Nanoscale science and engineering study and create materials and devices on the molecular scale. The Nanobiotechnology Center, a National Science Foundation supported Science and Technology Center, collaborated with Ithaca, New York's Sciencenter, a hands-on museum, and Painted Universe, Inc. an exhibition design-and-fabrication team, to create *It's a NanoWorld*, a 3,000 square-foot, hands-on traveling exhibition. Edu, Inc., an external evaluation group, led front-end research and formative evaluation to guide and refine development of the exhibition.

Summative evaluation investigated visitors' experiences and the degree to which the exhibition met its intended learning goals. Lessons learned were catalogued to guide development of future informal science education related to emerging technology.

The summative evaluation used a pre-post study to investigate what content children acquired and exit interviews to explore children's understanding of concepts presented as well as any misconceptions related to the learning goals. Exit interviews with teens and adults revealed the extent of their understanding of the exhibition and its science content. The summative study found that visitors said *It's a Nano World* is a fun, inviting, and engaging hands-on exhibition. Pre-test and post-test findings showed increased understanding of key science vocabulary—for example, "cells" and "nano."

After using the exhibition, most visitors were able to state that nano means tiny. During exit interviews 90 out of 100 adult visitors who used the exhibits could not give examples of nanotechnology or nanotechnology applications. Teaching adults about nanotechnology was not a stated learning goal. The evaluators emphasize that **this finding is not reported as a failing of the *It's a Nano World* team.** Rather it is to dramatically illustrate that using unmediated museum exhibits to introduce nanotechnology to visitors is a formidable challenge. This may be due in part to lack of nanotechnology applications that are hands-on or immediately relevant to visitors' lives.

A primary finding is that, in an informal learning situation, visitors benefit from mediation to understand emerging technologies that are based on scientific content that visitors may not understand. At Innoventions at Epcot® in Florida, for instance, 25 percent of early-elementary visitors in the pre study received illustrated children's books to introduce the exhibition's content and concepts. In the post study those visitors showed improved understanding of cells, nano, and nanotechnology compared to visitors who did not receive any background information prior to using the exhibition. Older children understood the meaning of models better than did younger children. The summative report presents findings from two days of summative evaluation at the Sciencenter in Ithaca, New York and four days of summative evaluation at Innoventions at Epcot®, in Lake Buena Vista, Florida.

The evaluation showed no significant differences in visitor learning or use of individual exhibits between the Sciencenter museum setting and Innoventions at Epcot® 'discovery park' setting (based on trackings, dwell time, exit interviews and the pre-post study). The primary differences between the venues were enhancements to the exhibition made by Innoventions at Epcot®, the presence of explainers, a larger audience and more diverse demographic at Innoventions at Epcot®. Visitors noted that *It's a Nano World* added a hands-on attraction to Epcot®. Interviews with 100 visitors at Innoventions at Epcot® found significant potential and support for aggressively marketing National Science Foundation sponsorship of the exhibition.

The development team is complemented for its credo that learning must be fun and engaging to successfully communicate content. *It's a Nano World* successfully met its goal of providing fun, educationally sound, hands-on activities to draw children in and help them learn.

Introduction

Nanoscale science and nanotechnolgy study and create materials and machines on the molecular scale. The Rand Corporation believes that emerging biotechnology, nanotechnology, and materials science "have the potential for significant…global effects by 2015" (Antón, Silberglitt, & Schneider, 2001)—that is, about the time when today's early elementary students are entering work or college.

The National Academy of Science stresses that education is "critical, because our success in developing, deploying and exploiting nanotechnologies will require synchronous innovation in how we educate and train our workforce, manage our R&D system, and prepare for and adjust to the expected and unexpected social and economic impacts of the new technologies." (National Academy of Science, 2000)

The potentially dramatic impact of nanotechnology challenges educators to give students the knowledge and understanding to become science-savvy adults in the emerging world of nanotechnology (Uddin & Chowdhury, 2001).

Educators from the Nanobiotechnology Center (NBTC) accepted this challenge. A National Science Foundation-supported Science and Technology Center, through a three-year collaboration with Ithaca, New York's Sciencenter, a hands-on museum, and Painted Universe, Inc. an exhibition design-and-fabrication team, to create *It's a NanoWorld*, a 3,000 square-foot, hands-on traveling exhibition. The goal of *It's a Nano World* is to introduce early elementary students (kindergarten through third grade) to a world they cannot see and to create a context for future learning about nanobiotechnology.

Comprehending nanotechnology requires understanding a world that cannot be seen. To appreciate nanobiotechnology, learners must cross, step by step, the macro-to-micro-to-nano bridge. Beginning with the visible macro zone, the ideal cognitive journey crosses into the sub-visible micro zone; the realm of cells and bacterium. Next the traveler moves into the nano zone, where learners encounter virus, DNA, molecules, and single atoms. Along the way these travelers realize the comparative size of things too small to see (cell is

larger than DNA; DNA is made of molecules which are made of atoms). Finally, there is a revelation that scientists can make things, such as machines and tools that are too small to see.

Front-end research sponsored by the *It's a Nano World* project shows that early elementary students, a primary informal-science audience, do not understand what they cannot see (Spencer, Angelotti, & Graham, 2001). During interviews and focus groups conducted as part of classroom activities with over 400 early elementary students, researchers discovered that the smallest thing that most children could think of is something they can see—for example, a bug or a grain of sand. Cells were often misunderstood and nano was an entirely unknown concept for most children and many teachers.

During two years of exhibition development, formative evaluation included iterative testing of exhibits, signs, and videos. Evaluation ensured that *It's a Nano World* presented accurate scientific content through fun, engaging, hands-on activities that children could understand.

On the basis of front-end research, the exhibit-development team articulated five outcomes or learning goals and used these goals as a basis for all exhibit concepts. Exhibit prototypes were tested and refined by interviewing children who interacted with individual exhibits. Over 600 children participated in formative evaluation over a two year period.

Evaluators conducted a two-part summative evaluation at the Sciencenter, a hands-on science museum in Ithaca, New York, and at Innoventions at Epcot®, in Lake Buena Vista, Florida. The evaluation investigated visitors' experiences and the degree to which the exhibition met its learning goals, and compiled the lessons learned to guide development of future informal science education related to emerging technology.

The summative study combined a pre-post study to investigate what content children acquired and exit interviews to explore children's understanding of concepts presented as well as any misconceptions related to the learning goals. Visitor-tracking software and visitor counts documented how people moved through the exhibition and used the individual exhibits. Exit interviews with teens and adults revealed their understanding of the exhibition and its science content. All data were meticulously documented in a relational database.

The summative study found that visitors said *It's a Nano World* is a fun, inviting, and engaging hands-on exhibition. Pre-test and post-test findings showed increased understanding of key science vocabulary—for example, "cells" and "nano." Children used tools to observe small things and, through the "Scope on a Rope" exhibit component and two videos, were exposed to things too small to see with their eyes.

Although children acquired some new vocabulary words and were repeatedly exposed to the concept of nano, some misconceptions persisted. There was little evidence that children or adults gained an understanding of the comparative size and scale of sub-visible objects (this was not a learning goal for children). After using the exhibit the majority of visitors knew that "nano" means extremely tiny.

The study finds that the exhibition successfully created a context for future learning about nanotechnology. This conclusion is based on tracking studies showing children's repeated and sustained use of tools to see normal things highly magnified, an increased post-visit understanding of cells, nano, and that cells are inside your body; 65 percent of children who drew macro objects pre also drew micro objects post.

A primary finding is that, in an informal learning situation (such as a museum or exhibition), visitors benefit from mediation to understand emerging technologies that are based on scientific content with which visitors may not be familiar. At Innoventions at Epcot®, for instance, 25 percent of visitors in the pre study received clear background information (printed booklets) to introduce the exhibition's content and concepts. In post-visit interviews those visitors showed improved understanding of cells, nano, and nanotechnology compared to visitors who did not receive any background information prior to using the exhibition. Innoventions at Epcot®, staff members corroborated that finding by reporting that visitors "stay longer and learn more when we explain it to them."

The summative study discovered that visitors did not read signs; rather, they said they would prefer information be presented in other ways—such as by cartoons, illustrated panels, and talking exhibits.

Not surprisingly, older children understood the meaning of models better than did younger children. The Innoventions at Epcot® 'discovery park' venue was successful in exposing large numbers of people to *It's a NanoWorld*. Visitors' comments showed that they were extremely satisfied with the exhibition and said that it added a needed hands-on component to Innoventions at Epcot®.

This study reports findings from a preliminary summative study at Sciencenter in Ithaca, New York and four days of summative evaluation at Innoventions at Epcot®. It begins with an introduction to the challenge of using informal science education to introduce nanoscale science and engineering to elementary-school students through a hands-on environment. A brief description of methodology is followed by a summary of findings. The report presents evidence of the team's success in meeting its stated learning outcomes. It then considers the difficult challenge of meeting higher-level goals of introducing complex science and technology content through models and mediation. It ends by considering the differences between the exhibition at two venues—namely, a small, hands-on science museum and a large 'discovery park' venue.

Problem Statement and Project Goals

> "The 21st Century workforce…the next generation of Americans…will require a solid grounding in mathematics, science, and technology."
> *Rita Colwell–Director of the National Science Foundation*

> "Our goal was to create an engaging exhibition for kids ages 5 through 8 to learn about the world that is too small to see with just their eyes."
> *Anna Waldron–Director of Education, Nanobiotechnology Center at Cornell*

Two Challenges

The Rand Corporation and other experts believe that emerging biotechnology, nanotechnology, and materials science "have the potential for significant…global effects by 2015" (Antón, Silberglitt, & Schneider, 2001)—that is, about the time when today's early elementary students are entering work or college. That point of view raises a larger issue—the need to build a national education infrastructure to encourage the technical and scientific literacy needed to understand nanoscale science and engineering.

Overarching Questions

The need to integrate nanoscience and its prerequisite concepts into **formal science** curricula and **informal science education** forces the simple question, "how do you help children learn about things they cannot see?"

That problem quickly leads to at least five research questions.

1) What are the developmental milestones and cognitive abilities affecting children's readiness to learn about and understand nanoscale science and engineering?
2) At what points do children develop the ability to understand sub-visible objects?
3) At what point do children develop the cognitive ability to understand the comparative size and scale of sub-visible objects?
4) What guidelines inform the use of models to represent objects that cannot be seen?
5) How should educators create pedagogical practice, activities, and examples to teach nanoscience and engineering in concert with existing curricula and science-education standards?

Exploring the efficacy of using informal science education to introduce nanobiotechnology to early elementary students through a museum exhibition raises large, complex, and interesting questions:

1) What is the cognitive ability of early elementary children (a primary science museum audience) to understand what they cannot see?
2) What informal science-education techniques effectively introduce the requisite concepts needed to understand nanoscale science and engineering (basic cellular

biology, atoms and molecules, comparative sub-visible size and scale, and the term nano)?
3) Can hands-on museum exhibits successfully introduce nanobiotechnology through an experiential exhibition?
    a. Can models introduce the tools and processes of nanobiotechnology?
    b. Do educational programs or mediated activities promote understanding of nanoscale science and engineering?

Clearly, full and meaningful answers to the above questions are beyond the scope of a limited evaluation. However, in these early days of nanoscience, *It's a Nano World* represents one seminal attempt to use informal science education to help early elementary children experience, understand, and appreciate what they cannot see as a basis for future learning about nanoscale science and engineering.

Learning Goals

During front-end research, the *It's a Nano World* team repeatedly discovered that "it is difficult for children to envision what they cannot see. If they haven't experienced 'smallness,' we need to provide concrete experiences of smallness. Direct experiences for children tend to dispel misconceptions" (Rockcastle, 2001).

Interviews with scholars and teachers, and focus groups with over 400 early-elementary children, helped the evaluation team to simplify and sharpen clear, realistic learning goals. The team's general goal was to help learners cross the macro-to-micro-to-nano bridge. Put another way, the exhibition team learned that to get to an understanding of nano, you have to go through micro.

The evaluation team defined five specific learning goals that frame the summative study of this exhibition.

1) The existence of the microscopic realm: *"Amazing things happen that are too small to see with just your eyes."*
2) Introduction to basic biological vocabulary needed to understand biotechnology (for example, types of cells in the human body, DNA, Virus, bacteria): *"There are many small things inside my body."*
3) Size and scale: *"Small things are made up of even smaller pieces."*
4) Elementary definition of "nano": *"Nano is really, really small."*
5) Introducing nanobiotechnology: *"Scientists and kids can use tools to observe small things."*

Understanding that early elementary children will find it difficult to understand the details of nanoscience, the team agreed that their overarching goal was to lay the groundwork and **create a context for future learning about nanobiotechnology**.

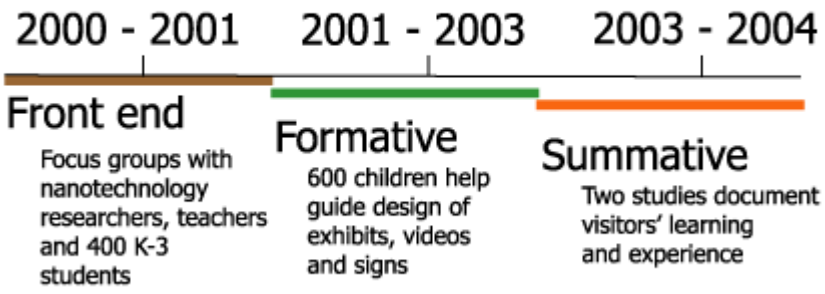
Methodology

Research versus Evaluation

The *It's a Nano World* project combined front-end research with formative and summative evaluation. To clarify those terms, we use Princeton University definitions—research is systematic investigation to establish facts or search for knowledge, while evaluation refers to ascertaining value or worth (1997).

Both terms are used to describe separate and distinct aspects of the *It's a Nano World* project. **Front-end research** during 2001 provided background information on children's readiness to learn prerequisite concepts needed to understand nanoscale science and engineering. Research protocols were prototyped and validated. The resulting data were meticulously documented and analyzed in a relational database. The findings from front-end research were used to inform informal education, but are easily applied to the design of curriculum and educational media.

Formative evaluation helped guide concept development and the design of prototype exhibits. **Summative evaluation** is limited to documenting visitors' experience at *It's a Nano World* and reporting findings related to the degree to which this exhibition met its stated learning goals.



Evaluation Timeline

Evaluation Questions

Three general questions focus the summative evaluation of the *It's a Nano World* exhibition.

1) What was the visitor experience at the exhibition?

2) To what extent does the exhibition meet its stated learning goals?

3) What lessons can be learned from the *It's a Nano World* exhibit to help articulate a model for national dissemination of nanoscale science and engineering and advanced technology through informal science education?

This study also documents the differences observed between the use of the exhibition in a small science museum (Sciencenter, in Ithaca, NY) and a large 'discovery park' venue (Innoventions at Epcot® in Florida).

Summative Evaluation Design

The evaluation divides the summative study into three sections: content and concept acquisition; use of the exhibition and exhibits; dissemination and lessons learned.

The study uses five data collection techniques:

1) Pre-post surveys and exit interviews examined children's acquisition of vocabulary and concepts.

2) Software-based tracking study, unobtrusive observation and visitor counts documented how the exhibition and individual exhibits were used by visitors.

3) Exit interviews with teens and adults gauged their satisfaction, understanding of exhibit concepts and interest in nanotechnology.

4) A signage study investigated adults' use of signs and solicited feedback on how to change or improve signage.

5) Interviews with Epcot® staff provided insight based on daily observation of and interaction with visitors.

All data sets are documented in a project database.

Findings

Content

> "This is really well organized. I wish I could bring my class of third graders. I could work this into science units several different ways."
>
> Third-grade teacher

Learning Goals

The evaluators feel strongly that the *It's a Nano World* team should be complimented for clearly defining their audience and establishing learning goals. For instance, the team dropped ideas and exhibits that were too complicated or simply did not work (as determined by front-end research).

During early formative evaluation, learning goals were clarified as the exhibition evolved. The team allowed learning goals guide the selection of exhibit concepts and design rather than the opposite. During the mid-formative evaluation phase, key content areas had clearly emerged. The team developed vocabulary lists and concepts for each area and linked that content to National Science Education Standards and New York Math Science and Technology (MST) standards.

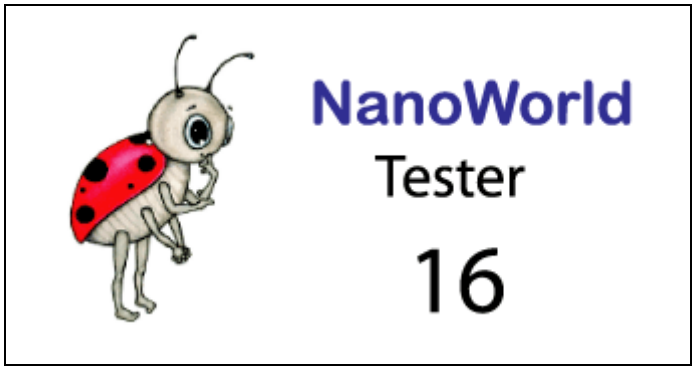
Data from the pre-post study (below) shows that visitors consistently got similar messages that match the project's learning objectives.

Ithaca and Innoventions at Epcot® Center Pre-post Study

On November 13, 2003, 116 children participated in a pre-post survey and exit interviews at the Sciencenter in Ithaca, NY. From March 5 through March 8 evaluators repeated the pre-post study with 101 additional children at Innoventions at Epcot®.

Smallest Thing

Children received a NanoTester badge and their age and gender were entered in a database. They received a coloring book with numbers corresponding to their badge.



Nano Tester Badge matched children to pre-post drawings and interviews.

The coloring book contained two pages. One page had a large blue square and the second page a large red square. Evaluators asked children to draw the smallest item that they could think of in the blue square.

Secret Word

When the children finished drawing, researchers asked the children to tell them the meaning of two secret words: "cell" and "nano." Evaluators engaged each child in conversation to draw out the child's understanding or misconceptions of cell and nano. Responses from each child were recorded in the database.

Using the Exhibition and Post-Test

When children were finished with the pre test (i.e., drawing in the blue square and talking with an evaluator), they used the exhibition with no guidance or interference from evaluators. As each child finished playing, they were directed back to the evaluator who asked the child to draw the smallest thing they could think of in the large red square on the second page of the coloring book. The interviewer–evaluator again asked the child to explain the meaning of the secret words "cell" and "nano."

Data Set

Smallest Thing

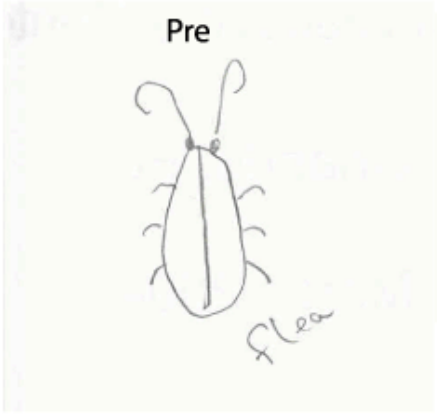
A total of 217 children participated in the pre-post study, 116 girls and 101 boys. After playing in the exhibit, 65 percent of the children (n = 141) drew a smaller thing during the post-test interview (red square) than they had during the pre test (blue square). Of the smaller things drawn, 72 percent had been presented somewhere in the exhibition.

Among those children who could not explain "cells" before using the exhibition, 15 percent were able to do so after interacting with the exhibition. Similarly, there was a 25-percent increase in the number of children who could explain, in simple terms, the concept "nano" after using the exhibition.

The following pages display examples of children's pre and post drawings. Drawings are followed by tables displaying sample results of pre-post understanding of cell and nano.

Female, age 6

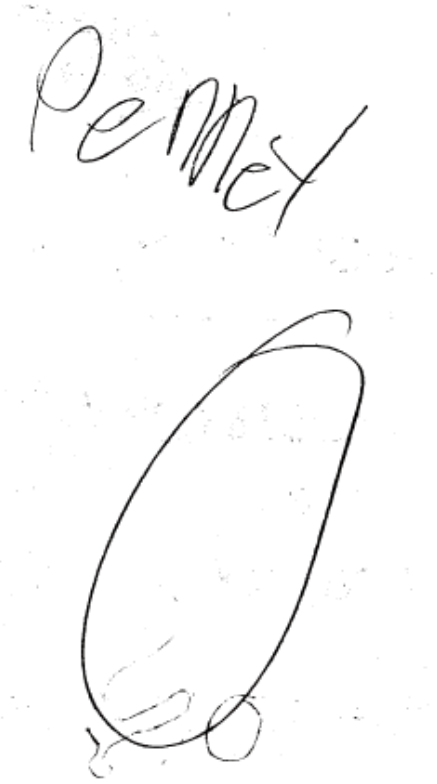
Pre



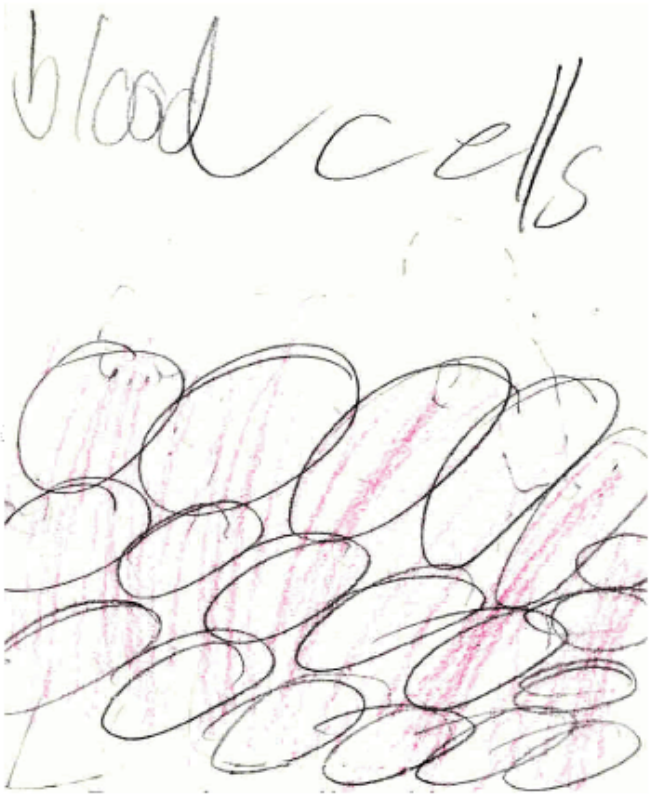
Post

Male, age 8

Pre



Post



Male, age 8

Pre

Post

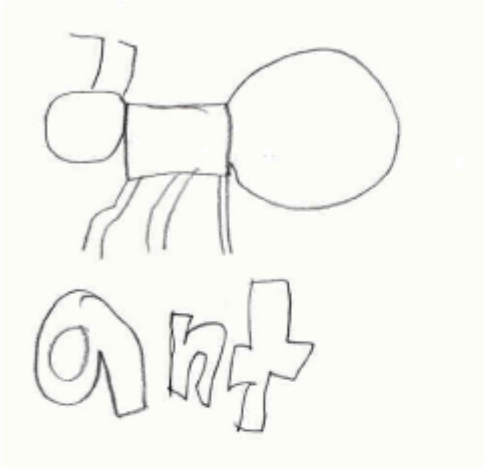
Female, age 8

Pre

Post

Female, age 8

Pre



Post

Male, age 9

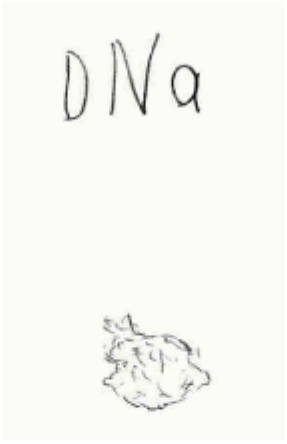
Pre

Post

Male, age 9

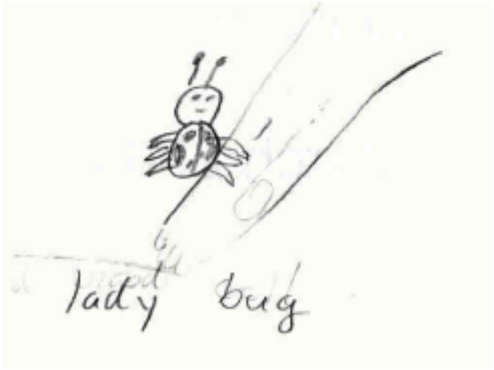
Pre

Post



Female, age 10

Pre



Post

Secret Word

Note on Tables: All comments shown in the tables below came from interviews at Innoventions at Epcot®. Children's comments from the same interviews at the Sciencenter study in Ithaca show an almost identical level of understanding.

Age	Gender	What is a cell? Pre	What is a cell? Post
6	Female	Don't know	A blood cell
8	Female	No idea	Something that's in everybody's body that's living.
8	Male	Cell phone	Those things inside your body that make blood
8	Female	No idea	Something so small you can only see it with a microscope

Children's post-visit explanations of cells showed greater understanding, but not profound knowledge. (All comments from Innoventions at Epcot®)

Age	Gender	What is a Nano? Pre	What is a Nano? Post
5	Female	I don't know	Small—Daddy told me
8	Male	Bugs, maybe	Too small to see
8	Female	Science	Something you cannot see because it's so small
9	Male	Smallest thing	Really, really small
9	Male	Tiny computer chip	Smallest piece of technology
10	Female	Bugs and cells and stuff	Teeny Tiny
10	Female	Small	Smaller than small—tiny.
10	Male	Don't know	Smaller than the tiniest things that people cannot see, even with microscopes.

Children were confident in their post-visit answers to what nano means.
(All comments from Innoventions at Epcot®)

Age	Gender	What is a Nano? Post
6	Male	Nanobot. Birds can be nanobirds.
6	Female	Something in a computer
6	Male	Big
6	Male	Bigger
8	Female	Fossils
8	Male	Planets
9	Male	How big or how small
10	Female	Little bugs/robots

Children showed post-visit misconceptions
(All comments from Innoventions at Epcot®)

The fact that children learned the meaning of cell shows that the exhibition met a primary learning goal. Children's answers revealed that simply acquiring the vocabulary words does not always imply an understanding of the concepts. When interviewed by evaluators, most children were unable to offer more than a rudimentary explanation of a cell. In keeping with findings of front-end research children were less able to articulate the meaning of DNA, virus, and bacteria than they were the meaning of cells and nano.

There was little evidence that children gained a detailed understanding of size and scale in the micro and nano range (this was not a learning goal). During post-visit interviews, adults and children could not differentiate between micro and nano. It is expected that children will not understand what they cannot see and that adults likely need direct experience and explanation to understand and articulate the differences between micro and nano. The fact that adults and children did not gain appreciation of sub-visible size and scale is not a

failing of the project, but evidence that hands-on exhibits are designed to deliver experiential learning more than facts, data and content.

The evaluators note that despite lack of acquisition of detailed content knowledge **the exhibition outcomes are in keeping with the learning goal of providing a basic, introductory understanding of cells and nano, and a context for future learning.**

Adults' Post-Visit Answers, "What is Nano?"

After using the exhibition many adults remained unclear about what nano meant. Some individuals' preexisting misconceptions persisted, while others who used the exhibition indicated that they had gained no new knowledge. Those that said they learned something about nano from the exhibition were the exception. Of special note is the pre-post-study comment from the woman below.

Evaluator: What is Nano?

Visitor: *Pre visit*—"It is a measure of magnification. Nano is a measure of small size. It's a measure of magnification or enlargement—I know the term nanometer. So clearly it is about measuring due to the presence of the word "meter."

Post visit—"I was wrong. It is length, not magnification. I learned that by measuring myself in nanometers."

Nanobiotechnology – A Difficult Concept for Exhibits

The line between content and concept can be hazy, especially with elementary-school-age children. Content, in this context refers to specific facts and information (all living things are made of cells). Concept refers to something conceived in the mind; an abstract or general idea derived from other information (Curiosity about what is nanotechnology and how it affects my life). For children and especially for adults, concept acquisition is an important basis for future learning.

The study used a meaningful question technique to examine the exhibition's success in helping visitors understand nano. This outcome is loosely related to one of the exhibition's conceptual learning goals:

- Amazing things happen that are too small to see with just your eyes.

Age	Gender	What is Nano? Post
15	Male	Tiny. I learned it in science, not here.
18	Female	I've heard of it but don't really know what it means. *(After spending 10 minutes in the exhibition)*
20	Male	I've never heard of it. *(After spending 11 minutes in the exhibition)*
30	Male	Nano means 10^{-9}—I saw it in the Movie *Power of I0.*
35	Female	You asked me that before. I still don't know. *(After spending seven minutes in the exhibition, including the use of photolithography)*
40	Female	Small, very small.
45	Male	How big or how small
55	Female	It's like Robin Williams [in the 1970s U.S. television comedy *Mork and Mindy*]—Nanu Nanu. *(After spending 15 minutes in the exhibition)*
60	Female	I know it because I work at Brookhaven Labs. My husband learned it through buying securities.

Adults' post-visit responses to the question, "What is nano?" (All comments from Innoventions at Epcot®)

Meaningful-Questions Technique

As part of the exit-interview process, evaluators wanted to learn what visitors thought the exhibition was about and what questions were left unanswered.

"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). In their work to design assessment for science inquiry, Mislevy, *et al.* (2003) present a technique that provides background information to a learner then helps the learner ask a meaningful question.

In the simplest terms, learning is a mental process that stems from asking or wondering. Understanding what people are wondering (their questions), partnered with skillful

interview, illuminates what they already know, their misconceptions, and what they seek to understand.

Children's Questions

During the post-test with children the interviewer spent several minutes talking with each child, asking "What do you not understand about nano?" and "What do you want to learn about nano?" (All comments from Innoventions at Epcot®)

Age	Gender	What do you not understand about nano?
6	Male	I don't even know what it is!
7	Female	Who's nano?
7	Female	What kind of stuff is that tiny?
8	Female	How do they do it? I mean, how do scientists work with things that small?
8	Male	What do you get from it? What kinds of things do they make?
9	Male	Why do they want to…
9	Male	What is it?
10	Male	How can scientists do stuff like that?

Age	Gender	What do you want to learn about nano?
5	Male	I don't want to know…
6	Female	How do they learn about things that you can't see?
7	Female	If it is too small to see how can you touch it?
7	Female	I want to learn about nanobots.
8	Male	I want to know how do scientists move nano things? They have big fat fingers and nano is really small. Do they use really small tweezers?
9	Male	How do they power the nanobots?
10	Female	How does this affect me and my friends?
10	Male	I want to know more about the pills that you swallow that have a camera that takes pictures of your insides. I think that is so cool.

Children were curious in their post-visit questions about nanotechnology. (All comments from Innoventions at Epcot®)

Adult's Did Not Understand Nanotechnology

This section presents evidence that adults could not explain the concept of nanotechnology after using the exhibition. Ninety percent of adults who were not told, pre-visit, that the exhibition was about nanobiotechnology, did not understand that the exhibition was about nanobiotechnology after they used the exhibition.

The evaluators feel this is an important and positive finding. **It <u>does not</u> indicate a failing on the part of the exhibition development team.** Teaching adult visitors about nanobiotechnology was not a stated learning goal. Inspiring curiosity and the desire to learn more about nanobiotechnology was a goal, and based on exit interviews, the exhibition accomplished this goal. The team should be complemented for a willingness to learn from what did not work and apply the lessons to future projects.

Rather the evaluators' intended audience for this section is program officers and reviewers at the National Science Foundation and other informal science educators. The message is simple but clear – because new and emerging science and technology is often advanced and 'content heavy', visitors need active help to understand new technology and its prerequisite content. Help may take many forms including but not limited to programs, video, animation and audio and interaction with explainers. Unmediated museum exhibits do not appear to provide enough help.

Conversations with Adults

During adult exit interviews the evaluators asked adults and teens the intentionally vague question, "What was this exhibition about?" Interviewers followed with Rogerian-type probing questions to clarify visitors' perception of the exhibition and the types of things that they learned.

The interviewer next asked specifically "Did you see anything about nano or nanotechnology?" and followed up with the questions "What do you not understand about nanotechnology?" and "What do you want to learn about nanotechnology?" (The first three comments were gathered at Sciencenter. Remaining comments were gathered at Innoventions at Epcot®)

"Did you see anything about nano or nanotechnology? What?"

No.

No. Nothing.

No. Nothing I saw.

No. I didn't see anything.

I read the sign and learned about the fact that scientists are developing tools at the nano level. I learned about the importance of sepsis in the process.

I saw the name NanoWorld, that's all. I want to understand the new frontier. This [exhibition] doesn't do that for me.

What's nano?

There's nano (pointing to the *Power of Ten* movie as the image approached the nano scale).

"I am a foreign tourist and don't speak English well. That (Powers of Ten) was excellent. It is the first time I have ever seen nano."

"What do you not understand about nanotechnology?"

I've heard about nano computers that can do amazing things—what's that about? (Sciencenter)

I don't know what it is and what it's used for.

How is the technology being applied now and where is it going?

I would like to know more about how nanotechnology will help with health care.

Crime scenes; I want to know how nanotechnology will help analyze DNA to find criminals.

Where do we apply this in science? What are we doing now and where will it take us? (Sciencenter)

"What do you want to learn about nanotechnology?"
Everything. What it is. *(after 15 minutes in the exhibition)*

What it's all about? How they do it; you know, the process they use in the lab.
I would like to see an end-product result. It would be nice for people to see what actually is built using this technology

I want to know about where this technology is going. What can we expect in the future?

I would like to see how this [nanotechnology] will impact our lives.

I am very interested in the way scientists are working to map cells and create tools to diagnose [disease]. At my age I'm very interested in health protection. *(Female, age 55)*

Experience

This section provides a summary of a visitor-tracking study, visitor counts by exhibit, and Innoventions at Epcot® Center visitor and staff members' comments about specific exhibits.

Tracking

A visitor-tracking study documented how people used the *It's a Nano World* exhibition. Exhibit evaluators used PeopleTracker™—proprietary software developed by Edu, Inc.—to track and time the movements of over 200 visitors. The software recorded demographic information, path of use, time in line, dwell time at each exhibit, and total time in the exhibition. Comparing those data across exhibits provides quantitative insight into the frequency and length of use of each individual exhibit. The tracking study was spread over a four-day period.

Hands-on Popular

The most frequently used and longest used exhibits were hands-on. Cell Sorters were used the most and the longest, followed by magnification exhibits (below) and pinball games. How Many Nanometers Tall was among the longest average use but used by fewer people, possibly due to it's location. It was very popular with families and groups.

Observing Small Things

The project met its learning goal of 'scientists and kids can use tools to observe very small things' by providing access to magnification tools. Tracking showed that visitors, especially children and families, spent considerable time at the exhibits that allowed them to use tools to magnify normal objects.

Out of 206 trackings 76 percent of visitors used the Magnification Station, 61 percent used Scope on a Rope. Both were among the longest used of the exhibits. Many visitors who did not use Scope on a Rope may have used it, had there not been a line.

Average visitor time at Magnification Station was nearly one minute. People used Scope on a Rope for an average of 1 minute and 23 seconds, second only to the Cell Sorter. The longest tracked time at Magnification Station was over four minutes and almost eight minutes at Scope on a Rope. Evaluators observed many uses longer than the tracked average. Innoventions at Epcot® staff reported that visitors regularly use these two exhibits for up to twenty minutes when crowd conditions allowed. An Innoventions at Epcot® staff person commented "Both of these are extremely popular. When it is quiet we will have families with young children sit at the magnification station for a half hour or more. Young children love it. I see people moving back and forth between the magnifying glasses [Magnification Station] and the Scope on a Rope."

It's a Nano World at Innoventions at Epcot®

Visitor Tracking Summary

March 5-8, 2004

Using PeopleTracker™, proprietary software developed by Edu, Inc., researchers tracked guest movement through *It's a NanoWorld*.

The software captured time at each exhibit along with guests' age, gender, and ethnicity. Researchers entered comments, recorded sign reading behavior and disabilities. Basic data and analysis follow.

Number of Trackings	206
Number of Tracked Exhibit Uses	1004
Average Time at Individual Exhibits	00:51
Average Time in Exhibition	06:03
Average Time at All Exhibits	04:24

Most Used Exhibits	Number of Uses	% Visitors Who Used	Longest Average Use	Average Use (min:sec)
Combined Cell Sorters	158	77%	Glow Cell Sorter	01:36
Magnification Station	157	76%	Scope on a Rope	01:23
Scope on a Rope	125	61%	Combined Cell Sorters	01:16
Dust Tippy Table	125	61%	How Many Nanometers Tall	00:55
Germ Launcher	96	47%		

Least Used Exhibits	Number of Uses	% Visitors Who Used	Shortest Average Use	Average Use
How Many Nanometers Tall	34	17%	Scale Gallery	00:33
Scale Gallery	39	19%	Look Closer	00:37
Video Theatre	54	26%	Giant Magnification Glass	00:37

Exhibit	# of Uses	% of Visitors Who Used	Average Time@ Exhibit	Shortest Time at Exhibit	Longest Time at Exhibit	% of Uses over One Minute
Giant Magnification Glass	77	37%	00:37	00:01	02:55	6%
Magnification Station	157	76%	00:49	00:01	04:38	28%
Scope on a Rope	125	61%	01:23	00:01	07:55	49%
Glow Cell Sorter*	90	44%	01:36	00:03	20:00	40%
Magnet Cell Sorter*	68	33%	00:55	00:01	05:40	32%
Video Theatre	54	26%	00:42	00:02	04:01	19%
Scale Gallery	39	19%	00:33	00:02	02:24	21%
Look Closer	64	31%	00:37	00:02	03:16	17%
How Many Nanometers Tall	34	17%	00:55	00:02	03:12	47%
Power of 10 Video	48	23%	00:43	00:02	03:01	29%
Dust Tippy Table	125	61%	00:44	00:01	33:37	14%
Germ Launcher	96	47%	00:38	00:01	10:41	9%
Entrance	0	0%	00:00	00:00	00:00	0%
		Average Exhibit Use	**00:51**			
* Combined Cell Sorters	158	77%	01:16			

Counts of Visitors Using Exhibits

Counts of visitors using individual exhibits at Innoventions at Epcot® provide a secondary quantitative measure to compare and contrast with visitor tracking data. In its simplest form it shows which exhibits people used the most at a given time and over the course of a day. Two researchers conducted alternating counts at random intervals five to fifteen minutes apart. The study was conducted over the course of one day, March 8, 2004. Researchers made 24 counts during a high visitor traffic period – 9:45 AM to 1:25 PM.

Exhibit	Total Number Recorded Users	Average Users at One Time*
Entrance		
Gateway	5	0.21
Look Closer! Can You Guess What I Am?	61	2.65
How Many Nanometers Tall are You?	72	3.00
Magnification Station		
Giant Magnifying Glass	52	2.17
Magnification Station	161	6.71
Scope on a Rope	99	4.13
Movies		
Movie	53	2.22
Powers of Ten Film	49	2.35
Adventures in Tiny Things		
Dust Tippy Table	53	2.29
Germ Launcher	50	2.63
Cell Sorter	191	11.94
Power of Ten Video	68	3.09
Photolithography	12	0.50
Scale Gallery	6	0.25
You are Made of Cells	5	0.21
Total number of uses during count	958	
Average number of visitors in exhibition at one time	39.79	

Note: Average Users at One Time displayed as a decimal means the exhibit was used infrequently.

Total Number Recorded Users in Descending Order

Exhibit	Users
Cell Sorter	191
Magnification Station	161
Scope on a Rope	99
How Many Nanometers Tall are You?	72
Power of Ten Video	68
Look Closer! Can You Guess What I Am?	61
Movie	53
Dust Tippy Table	53
Giant Magnifying Glass	52
Germ Launcher	50
Powers of Ten Film	49
Photolitography	12
Scale Gallery	6
Gateway	5
You Are Made of Cells	5

Favorite Exhibits

Fifty children at Innoventions at Epcot® were asked to name their favorite exhibits. The table below presents the total responses for each exhibit. Some of the children's spoken comments are presented below the table.

Scope on a Rope – 15	Magnifying Glass – 5	Powers of 10 Video – 1
Cell Sorter – 14	Magnification Table – 4	Look Closer – 1
Everything – 6	Germ Pinball – 3	Measure Yourself – 1

Scope on a Rope because "I can see the bottom of my shoe." *Male age 5*
Father says "Hands-on is great!"

"The Cell Sorter." *Male, age 6*

"The Cell Sorter was my favorite but I loved everything." *Male age 7*

"I loved the Powers of 10 video. What's even tinier than nano?" *Female age 8*

"Everything was fun!" *Female age 8*

"Scope on a Rope because you get to see what things really look like." *Female age 8*

"Powers of 10 video." *Male age 8*

"I liked it all." *Female, age 9*

"Cell Sorter." *male age 9*

"Magnifying Table. You could see things up close." *Female, age 9*

"My favorite exhibit – Look Closer I like to guess things." *Female age 9*

Recommendations for the Field

Models, Mediation, Interest, and Setting (Innoventions at Epcot® vs. Museum)

Models

> Visitor: "That's a failed exhibit."
>
> Evaluator: "Which one?"
>
> Visitor [smiling]: "The one with the mob of kids waiting to use it."
>
> Evaluator: "Ah, the Cell Sorter."
>
> Visitor: "Yes. It's a failed exhibit because it represents a piece of equipment the kids have never heard of. It sorts balls that represent cells–a second layer of symbolism. Of course most kids have never seen a cell so the analogy is weak to nonexistent. The kids are supposed to sort the cells into groups that make no sense, for a reason they don't understand. [pause] It looks like a lot of fun! You can tell they absolutely love it. I'm going to see if I can fight my way in."
>
> *—Ph.D. engineer and science educator*

Gilbert and Butler (2000) suggest that models and modeling play a central role in the nature of science, as well as forming a bridge to technology. They therefore have "an important place in both the formal and informal science education." Models in the context of *It's a Nano World* indicate objects that represent sub-visible items (e.g., balls representing cells and pinballs representing dust, germs, or pollen). This use of the term "model" is not to be confused with mental models, which are descriptions of cognitive representations of concepts or processes.

Research on the efficacy of models is beyond the scope of a summative evaluation. The following brief section presents visitors' comments, Innoventions at Epcot Center staff members' observations, and evaluators' insights on the challenges and successes of the models used in *It's a NanoWorld.*

Experiment–Models of the Sub-visible

The Nano World team chose to include models in the exhibition, aware that:

1) Understanding models requires that users have the ability to engage in abstract thought; and
2) Early elementary children age seven and younger, according to the Piaget Pre-operational Stage, are unable to conceptualize abstractly (Piaget, 2000).

Conscious in their choice to attempt a limited number of activities based on models, the team also made provisions for the youngest visitors. Formative evaluation of the pinball games showed that some of the children—seven and eight year olds—were able to articulate that pinballs represented germs and pollen. Adding simple, carefully tested audio explanations helped those younger than seven to get a series of key ideas about germs, dust, and pollen.

In the case of the Cell Sorter exhibit, the team designed it to also promote sorting and classifying, a recognized early science education skill for young children. The Blood Drop with its 5,000 red blood cells provided a fun anchor exhibit in addition to modeling red blood cells and white blood cells.

Observations

The following bullet points are informal observations from the evaluation team, some of which are obvious or reflect common sense. While the observations might be considered 'truisms', they lack the rigor and support to be considered formal research or recommendations for the field.

- Models were more easily understood when referring to familiar and known concepts, such as pollen and germs.

- The Cell Sorter as a model was ineffective because children had no point of reference. When 25 adults and 25 children were asked "Do you know what that exhibit is supposed to represent?," the only correct response came from a University of Florida doctoral candidate doing research in microbiology.

- Manipulation and mediation (explanation) seem to increase understanding of models.

    - Of 25 people observed using the photolithography model, six were able to explain it correctly. Those six carefully read and reread the sign and experimented with the exhibit several times.
    - A woman commented, "If you somehow told me how this process worked rather than making me read it, I would have understood immediately. I worked at it because I wanted to understand. Most people won't do that."
    - An obviously intelligent 12-year-old suggested that if you could manipulate the mask, shine a light through the mask onto the wall or a large screen, and feel the surface of the silicon wafer it would be easier to understand the photolithography process.

- The model needs value and payback. Value depends on the user, their age, interest and understanding.

    - "I liked Germ Pinball because it teaches you germs in a fun game."

      Boy age 6

- "I learned that you need to wash your hands to prevent germs. Big deal."
  Boy age 8

- Obscure examples and deeply embedded content are not successful.
  Evaluator: What does this machine do?
  Seven year-old: It sorts balls.
  Evaluator: What are the balls?
  Seven-year old: They're balls. Wooden I think.
  Evaluator: Do they represent anything?
  Seven-year old: You're supposed to suck them up.

- Balls in the Giant Blood Drop exhibit represented cells.
  - In pre-post activity (as explained earlier), several children who drew macro objects as the smallest thing they knew prior to using the exhibits drew a blood drop (or red balls) as the smallest object that they knew after interacting with the exhibits.
  - When questioned, the children explained that the balls were symbolic.
    Evaluator: You drew an ant before and now you drew a ball. Isn't a ball bigger than an ant?
    Six-year-old: It's a cell from the blood drop.
    Evaluator: Can you see a cell with your eyes?
    Six-year-old: They [the balls] aren't really cells, but they are supposed to be. They are like cells except they are bigger so you can see them.

An untrained observer would agree that models did not provide an experiential introduction to nanobiotechnology. In the case of the Pinball and Blood Drop exhibits, based on interviews with children and their parents, those models appeared to deliver a basal primer of concepts needed to build background for future understanding. In other words, the models helped learners cross the macro-to-micro bridge, but did not successfully make the micro-to-nano connection.

A larger observation is that while a hands-on exhibit can effectively model the experience of centripetal force or other principles of physics, an unmediated science exhibition is not designed to be and may not be the proper medium to accomplish the difficult task of introducing the sub-visible through models.

With mediation—that is, when staff members explain the models—the model proved more effective.

Mediation

"Parents and teachers who visit exhibits like *It's a Nano World* need information to become a quick authority on nanoscience so they are able to help children and answer their questions"

Dr. Susan Stratton
Professor of Elementary Education

Based on the outcome of the summative evaluation for *It's a Nano World* when it was based at Ithaca's Sciencenter, it was clear that both adults and children were very interested in the topic of nanoscience, but need more explanation than supplied. (Programs and mediation were not a part of the original Nano World project.)

To test the effect of mediation the evaluators used two techniques–a children's book and "Nano Facts" – a short oral introduction.

Children's Book

The evaluation team commissioned production of a simple children's picture book to introduce the main ideas and images of the exhibit. Parents of 25 percent of the children in the pre-post study were asked to read the book to their children after the child drew the smallest thing they knew but before the child used the exhibit.

Evaluators observed, and the data support, that when parents carefully read the book to children who were interested and attentive, those children showed greater understanding of cells and nano during the post-visit interviews. Moreover, relative to the other kids who explored the exhibits, children in the book sample seemed more articulate and confident when explaining the sub-visible object that they drew post-visit (typically a cell, germ, virus, or "adam" [sic]), and more readily gave examples of sub-visible objects that they had seen in the exhibition.

An evaluator noticed a three year old who had listened to her mother read the book to an older sibling. The three year old was sitting by herself on the floor of the movie theater, matching images of cells in the book to the corresponding image in the movie saying "cell."

Adults

In the pre-post study with adults, after completing the pre interview, evaluators briefly used the 'Nano Facts' talking points to introduce the concept of nano and nanotechnology.

The adults' exit interviews revealed that a majority of the adults did not know that the exhibition was about nanotechnology. However, of the 25 adults who received additional explanation before visiting the exhibits, nearly all were able to refer to examples of nano and nanotechnology in the exhibition and had questions about the technology. While far from conclusive or comprehensive, this example seems to indicate that mediation and exposure to key concepts increased adults' knowledge acquisition about nanotechnology– if for no other reason than they know what they are supposed to be looking for.

Alternatives to Signs

Observation during 200 tracking studies and interviews with visitors showed that the majority of visitors do not read signs. When asked to choose possible alternative to signs, a particularly popular source of information was interactive touch-screen "video signs"

that let users choose answers to their questions from a menu of rich media content. (Rich media refers to providing content through a combination of video, audio, animation, and illustrations rather than text-only explanations.)

Innoventions at Epcot® Staff Members Request Talking Points

During interviews, Innoventions at Epcot® floor staff that help orient visitors to exhibits, answer guests' questions and help visitors navigate through the exhibits made it very clear that they want written talking points to help introduce the exhibition and nanotechnology. It should be noted that the project team provided a short "primer" for all Innoventions at Epcot® staff that included a description of each cluster. Clearly, more intensive staff training would be helpful, given the complex nature of nanoscale science and engineering.

The following comments each come from a different staff member.

"As a presenter, if I talk to people about an exhibit, they stay in the exhibition for 45 minutes. When I don't talk, they leave in three to five minutes. We need talking points so we know how to engage guests."

"Guests have questions and they are shy about asking, so they leave. When I anticipate their questions and help them understand an exhibit, they are fascinated and stay longer. When I explain what's going on, I see parents go get their kids and drag them from other areas to look at NanoWorld."

"When this [exhibition] first came here we had no clue what it was about or how to answer guests' questions. Most of us had never heard of nanotechnology. I saw people making up answers for awhile. After we started learning what the exhibition was about I felt better and more confident talking with guests. Nobody wants to feel stupid."

"Nanotechnology is hard. I loved science and took biology in college, but it took me awhile to catch on to this and I'm still not sure I know that much. I'm afraid some college professor is going to ask me a question and trick me. You don't know who these guests are. It would really help having some information so you know what you are talking about. Better for us, better for guests."

Building Interest in Nanobiotechnology

The exhibit-development team articulated a set of secondary goals for the ideal visitor experience. One of those goals was to "Inspire curiosity so the visitor wants to know more about nanobiotechnology."

Exit interviews with adults show their near total interest in the subject area. Common themes that emerged from the exit interview question 'What do you want to know about nanotechnology?" included: What is nanotechnology? How will it affect our lives? How will it make our lives easier? Where is it going? How do we separate science fact from science fiction? What consumer applications—such as faster computers and smaller cell

phones—will result? "How will it impact medicine" was the most common question asked during exit interviews.

The exit interviews also exposed common misconceptions of technology that does not exist, such as diagnostic nano-sized video cameras that are injected into the skin or taken as a pill.

Differences between Innoventions at Epcot® and Ithaca's Sciencenter

Evaluators' observations and visitor and staff members' comments illuminate some of the differences between *It's a Nano World* as presented at Innoventions at Epcot®, a large 'discovery park' venue, and the Sciencenter, a small science museum.

Exhibition Enhanced

To meet Florida's codes and receive the necessary permits, the Sciencenter reengineered electrical and other specifications so that *It's a Nano World* could meet the demanding safety standards of Innoventions at Epcot® large venue. The professionals at Innoventions at Epcot® worked with the project team to adapt the exhibition to a large, high-traffic venue. Adding a projection screen to the *Power of Ten* video made the exhibition significantly more captivating and "big time" than it appeared at the small-venue Sciencenter. The big screen movie also had the *de facto* effect of creating a separate exhibit that visitors could interact with privately from a distance. Colorful "content banners" suspended from the ceiling at Innoventions at Epcot® added to the exhibition's overall appearance. The stage lighting at Innoventions at Epcot® gave the exhibition a different feel. A subjective observation is that at the Sciencenter, Nano World felt like an exhibition, and at Innoventions at Epcot® it felt like an environment.

Explainers

Explainers (e.g., exhibit guides) were present at Innoventions at Epcot® while at the Sciencenter the exhibition was unattended. By observing the experienced explainers work with visitors at Innoventions at Epcot® it was clear that visitors' experiences were enhanced by the mediation. For instance, Scope on a Rope was a popular, fun, and engaging exhibit at Sciencenter, but no one showed visitors how to use it. At Innoventions at Epcot® an explainer approached families and used the low-power scope to show them how hidden features of a five-dollar bill are visible under magnification. This simple example, which clearly showed visitors that ordinary things are made up of smaller parts, enhanced the Scope on a Rope experience for those Innoventions at Epcot® users.

This point cannot be over emphasized – the presence of properly trained staff members within the exhibition space is a powerful advantage for promoting informal science education to large audiences.

Kind of Visitors

An obvious advantage that Innoventions at Epcot® holds is that it draws a more diverse crowd than does even a well-attended urban science museum. It is generally agreed in the

museum community these classes of individuals are not a dominant visitor demographic to hands-on science museums: adult couples by themselves, retired couples, and senior citizens without grandchildren. At Innoventions at Epcot®, those types of individuals were present.

Conspicuous in their presence at Innoventions at Epcot® were groups of teenagers aged 16, 17, and 18, an audience that is often absent at science museums. Perhaps it was because the site visit was scheduled during early March, when many colleges schedule spring break, but there were also many college students at Innoventions at Epcot®, a group not regularly found at science museums. Innoventions at Epcot® attracts a diverse, international clientele, which has implications for developing signs and scripts for talking points for those that don't read English.

Number of Visitors

Innoventions at Epcot® officials estimate that by June 1, 2004, 795,000 people attended *It's a NanoWorld* at their venue. That audience likely exceeds the combined total number of visitors who would experience *It's a Nano World* during its multi-year tour of small museums through ASTC exhibition-rental service.

Potential Exposure for NSF

The size of the Innoventions at Epcot® audience presents tremendous potential for National Science Foundation exposure and name recognition. To gauge support or resistance to government funding of education at a for-profit venue, evaluators asked 100 people these two questions:

1) Do you know who sponsored this exhibition?

> No one did although National Science Foundation logos are present on both the signage and in the video displays. Many felt the funder might be IBM or Microsoft. Most had never heard of the National Science Foundation. An interviewer intentionally interviewed a woman who just finished reading a sign crediting NSF with funding the exhibition. She was not aware of the funder.

2) Do you have any concerns about government funding of an exhibition at Innoventions at Epcot®?

> Only five out 100 people expressed any reservation. The remaining 95 percent expressed positive reactions ranging from supportive to enthusiastic.

Representative answers include:

"No concerns. It makes sense. The government should support education about making things smaller and how we are moving to the future."

"I think it's good. Kids need fun education."

"It's education. I think it's a good thing. It's no different than schools. The government pays for schools. Why shouldn't they pay for learning here?"

Fit with Innoventions at Epcot®

When she learned the exhibition was bound for Innoventions at Epcot®, a parent visiting the Sciencenter noted "A science museum is a fun and full of play but it is also an implied learning experience, if not for children than at least for parents and teachers. An exhibit like this one is an opportunity for structured pre and post activities for school groups that won't happen at a place like Innoventions at Epcot. At Sciencenter *Nano World* is the headliner; at Innoventions at Epcot® it will be just one activity in a day-long visit."

An evaluator observed (paraphrased): "Epcot® is about rides, food, and entertainment. It is an implied future experience. Epcot®'s emphasis on the future offers a seamless fit with an emerging technology topic like nanoscience."

Innoventions at Epcot staff members and evaluators independently noted that visitors, especially kids, seemed to use the exhibition in synch with other activities in the building, by moving back and forth among them.

Another evaluator noted: "For many visitors Disney is fast paced, hurry up, and get to the next exhibit. So it is not the parent's intent to stay in one place for too long. In a museum where there is less to do, children often spend time with each exhibit to learn—not just to play and be entertained."

An Innoventions at Epcot® staff member countered: "Nano offers a quiet space where people can sit down and spend time. No other exhibit at Epcot does that. Some people stay here 30 minutes or more. That's very unusual at other Epcot attractions."

A professional staff member at Innoventions at Epcot® commented: "I spoke with the father of a three-year-old who had been playing with the cell sorter for 45 minutes. He said we came here for her, and if this is what she wants to do, this is what we will do."

A mother said: "This is my kid's favorite activity so far and we've been through the entire building."

Something New for Epcot®

An unexpected insight for the evaluators was not the effect Innoventions at Epcot® had on the exhibition–but rather the effect *Nano World* had on Epcot®.

Several visitors, in different ways, said: "this is the only hands-on activity we have seen here."

A local parent noted: "We live in Orlando and come here several times each year. This is great because my six-year-old boy usually comes here and heads straight to the computer games. This is a nice alternative for him; the hands-on activities are good. They give him a chance to experiment and explore. They need more of these kinds of activities here. I was disappointed when I learned it was a traveling exhibition."

A grandparent remarked: "I live in Orlando and bring my grandchildren to Epcot® every year. My grandson has already asked if we can come back and do this (*NanoWorld)* next year."

Effect on Innoventions at Epcot® Staff

A long-time Epcot® staff member said: "This exhibit has enlivened and engaged the staff. They have to be awake and think when they work in *NanoWorld*."

Epcot® staff members approached the evaluation team thinking that its evaluation would end up removing the exhibition.

An Epcot® staff member, choked with emotion, said: "I hate to see it go. I will be so angry if they don't keep this. It is so popular and different than anything here. People love it."

Finally, this from another Epcot® staff member: "We like it. We don't want it to go."

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Appendix A

Explanation of Protocols Used at Innoventions at Epcot®

***It's a NanoWorld* at EPCOT**
Proposed Evaluation Protocols
November 24, 2003

As a condition of funding, the National Science Foundation requires external evaluation of how visitors use the exhibition and what they learn. The evaluation improves future exhibitions and guides NSF funding decisions.

Three researchers will work with 100 family groups and 100 children over four days. There are two protocols. Adult interviews last two to three minutes. Family interviews last three minutes pre and three minutes post.

Adult Entry Exit Interview and Tracking

The purpose of this protocol is to:

1) Use pre and post interviews to document visitor's understanding of nano before and after using the exhibition.
2) Document the visitor's perception of what the exhibition was about
3) Record which exhibits the visitor uses and for how long

This protocol asks adult visitors one pre question. Researchers unobtrusively observe and track the visitor's use of the exhibition. As the visitor leaves the exhibition they answer seven exit interview questions. The exit interview takes two to three minutes.

The goal is 100 trackings and interviews. Please see the protocol number one Adult Entry Exit Interview.

Family Group - Kids Pre and Post Drawing

The purpose of this protocol is to use pre and post drawings to document how children age 5-8 understand things too small to see before and after using the exhibition.

With their parents present, children draw the smallest thing they can think of and are asked a single question: "What does nano mean?'.

Children use the exhibition. When they are done they again draw the smallest thing they can think of and answer post visit questions.

The exit interview takes three minutes. The goal is 100 trackings and interviews. Please see the protocol number two Child Entry Exit Interview. To see if visitors benefit from extra help before using the exhibition 25 of the 100 children will hear a two minute children's story called *Too Small to See.*

Adult Entry-Exit Interview

This protocol asks adult visitors one pre question. Researchers unobtrusively observe and track the visitor's use of the exhibition. As the visitors leave the exhibition they answer four exit interview questions. The exit interview takes two to three minutes.

ID: Gender: M / F Age: 18-27 27-40 40-55 55-70 70+

Adult Pre-Interview

1. What do you think of when you hear the word 'nanotechnology'?

Adult Exit Interview

Perception and questions about nanotechnology

2. What was the exhibition about?

3. Did you see anything about nano or nanotechnology? What?

4. What do you not understand about nanotechnology?

5. What do you want to learn about nanotechnology?

Child Pre-Interview

1. We are going to play a game called secret word. Quietly tell me what does the word cell mean? (Probe – Have you ever heard that word? What is a cell? How would you describe a cell to a younger kid?)

2. Quietly tell me what does the word nano mean? (Probe – Have you ever heard that word? What is nano? How would you describe nano to a younger kid?)

Child Exit Interview

Perception of small things

3. We are going to play secret word again. Quietly tell me what does the word cell mean?

    Optional depth of understanding probe questions

    a. How big are cells?
    b. Can you see cells?
    c. Where do they live?
    d. Did you see anything about cells when you were playing with the exhibits in this room? Where?

4. What does the word nano mean?

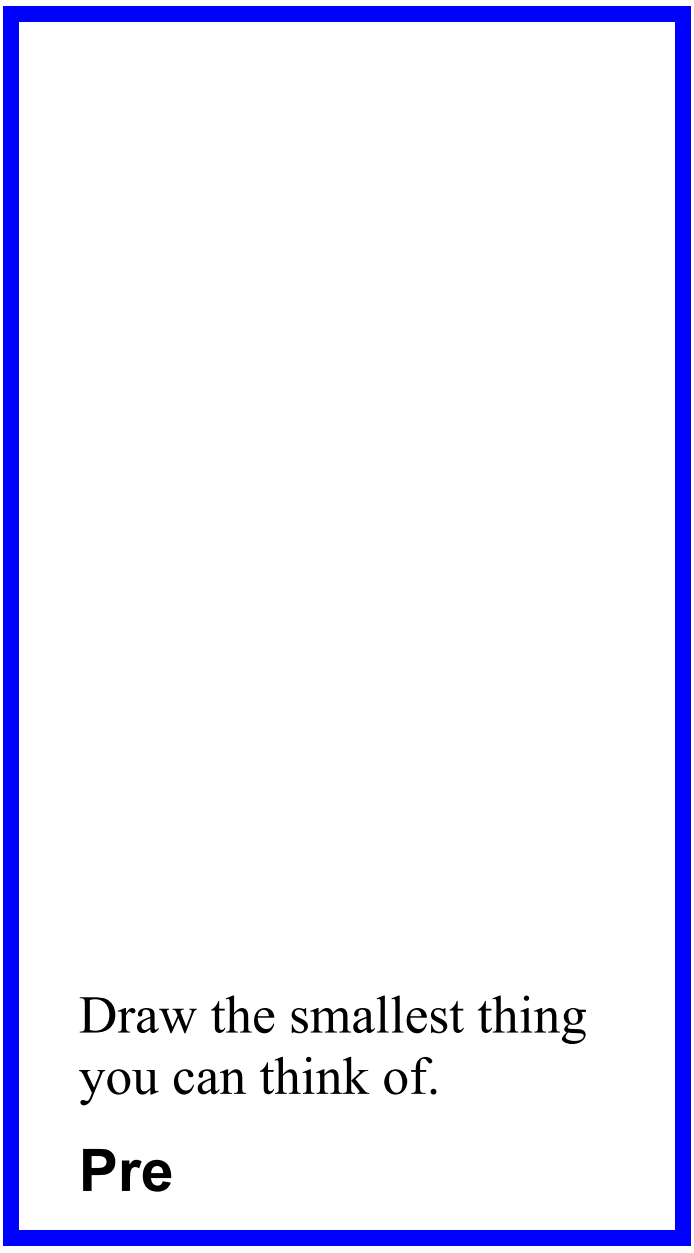
Perception and questions about nanotechnology

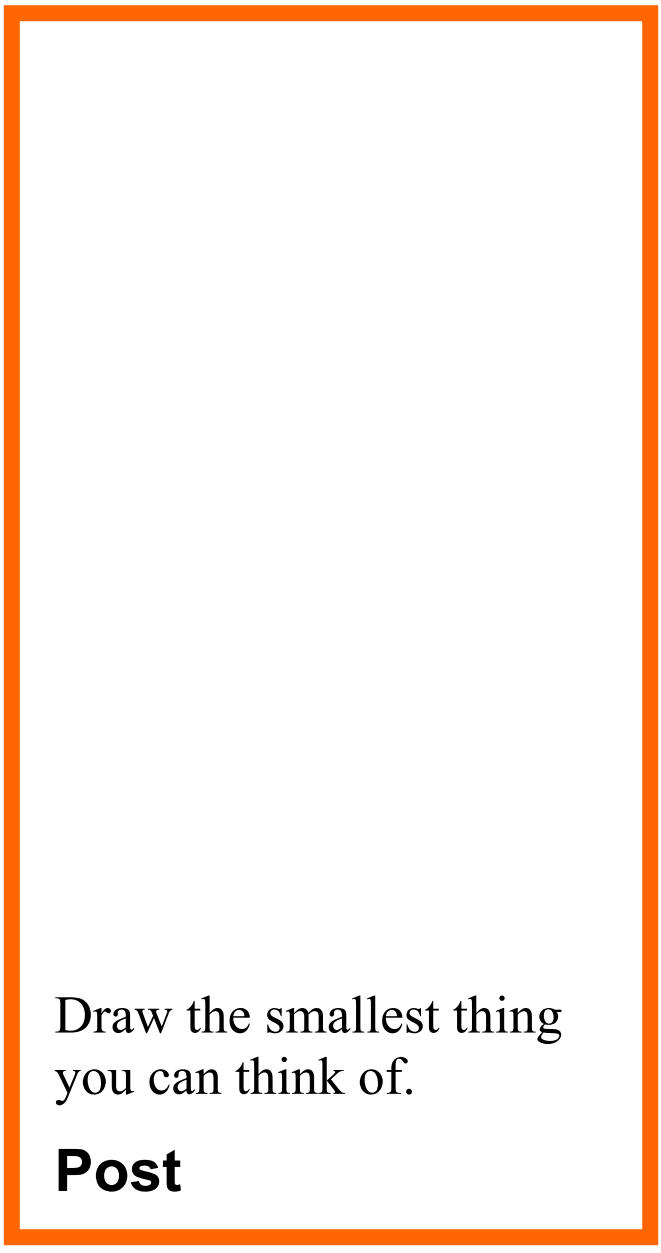
5. What do you not understand about nanotechnology?

6. What do you want to learn about nanotechnology?

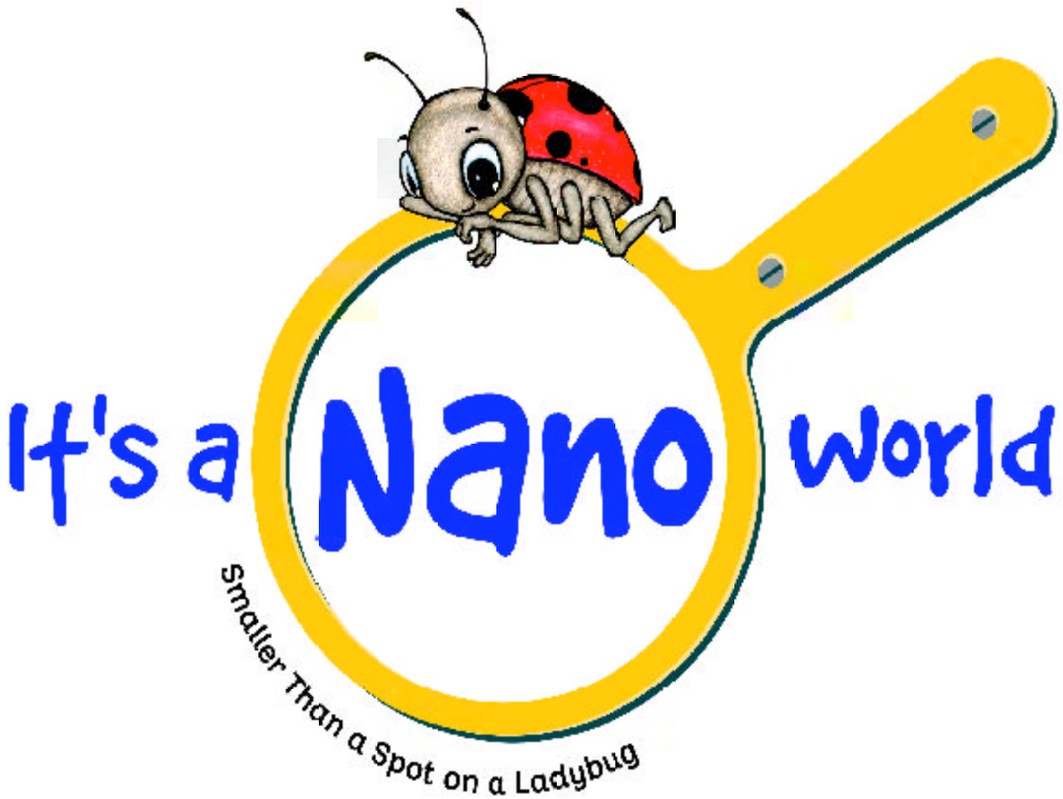
Smallest Thing Pre–Post Coloring Book

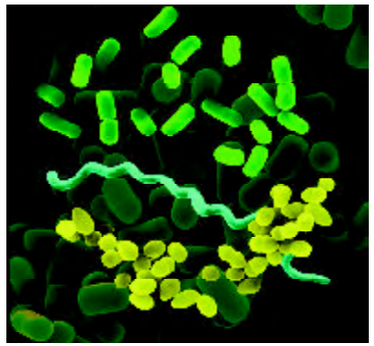
If found please call toll free: Edu, Inc. 866.433.8462	Smallest Thing Epcot Discovery Center Orlando, FL March 2004 Badge 88

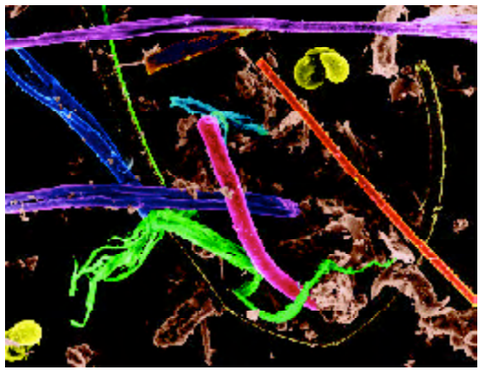

Draw the smallest thing you can think of.
Pre


Draw the smallest thing you can think of.
Post

Children's Book Pre–Post Study



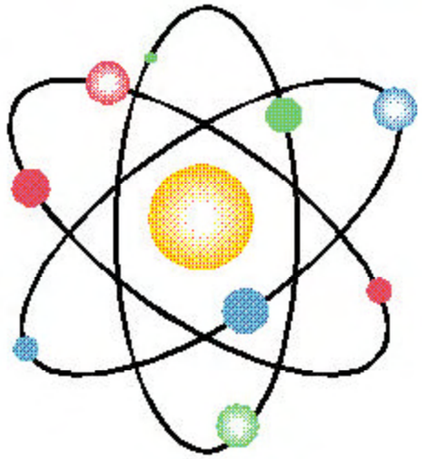




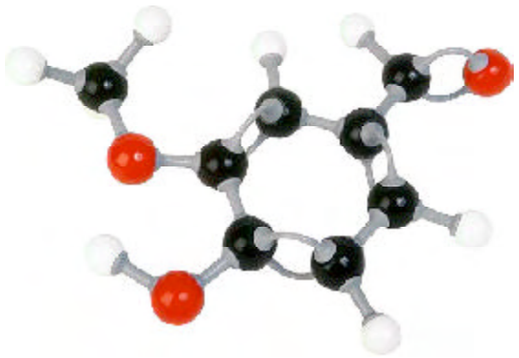
I am a ladybug.
You think I am small?

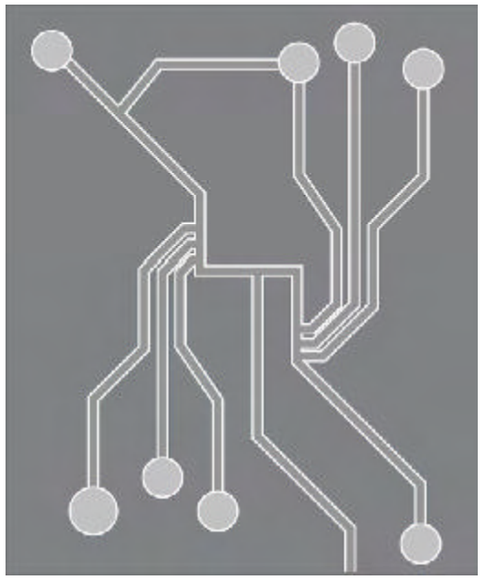
Germs, cells and dust are smaller than me.

Nanozone

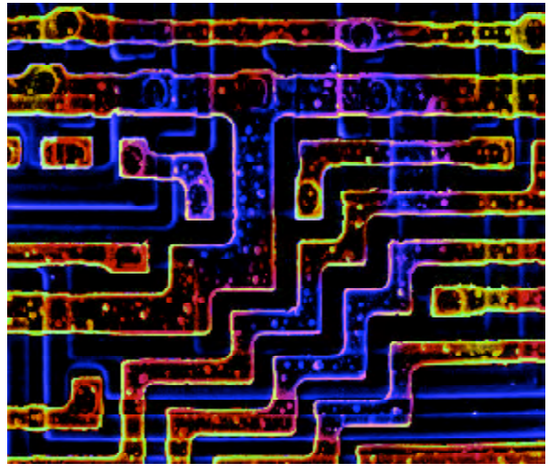


atom





cell sorter chip



computer chip

Nano things are tiny.
They are too small to see.

Now listen closely.
This is hard to believe.
Scientists make tools that are too small to see.

Macro zone

Micro zone

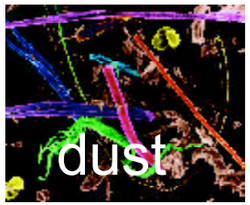
Nano zone

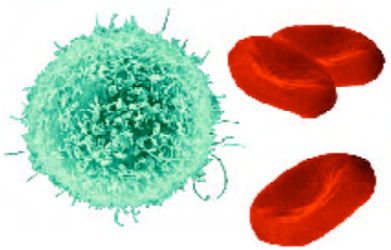
There are three zones that you need to know.
Things get smaller in each zone you go.

Macro zone

Macro things are big.
You can see with your eyes.

Micro zone

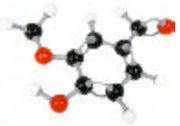




blood cells

Micro things are small.
You need a microscope to see them at all.

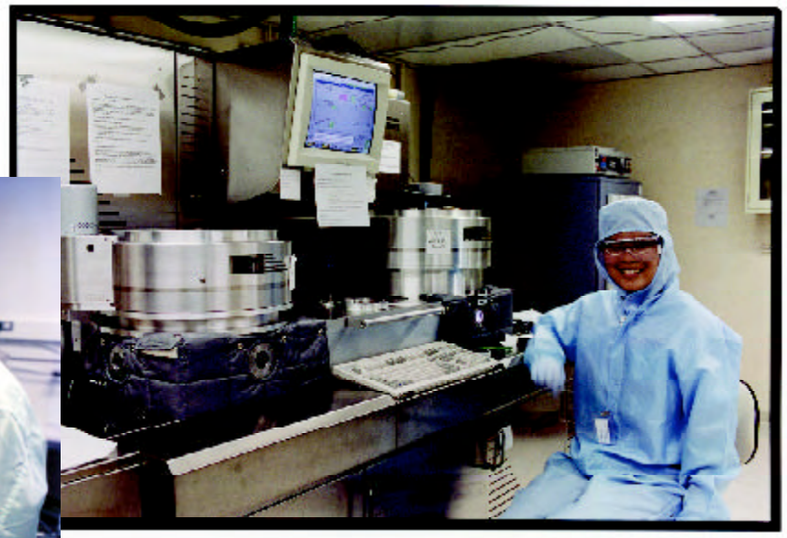
Nanozone



molecule

atom

Things that are nano are too small to see.



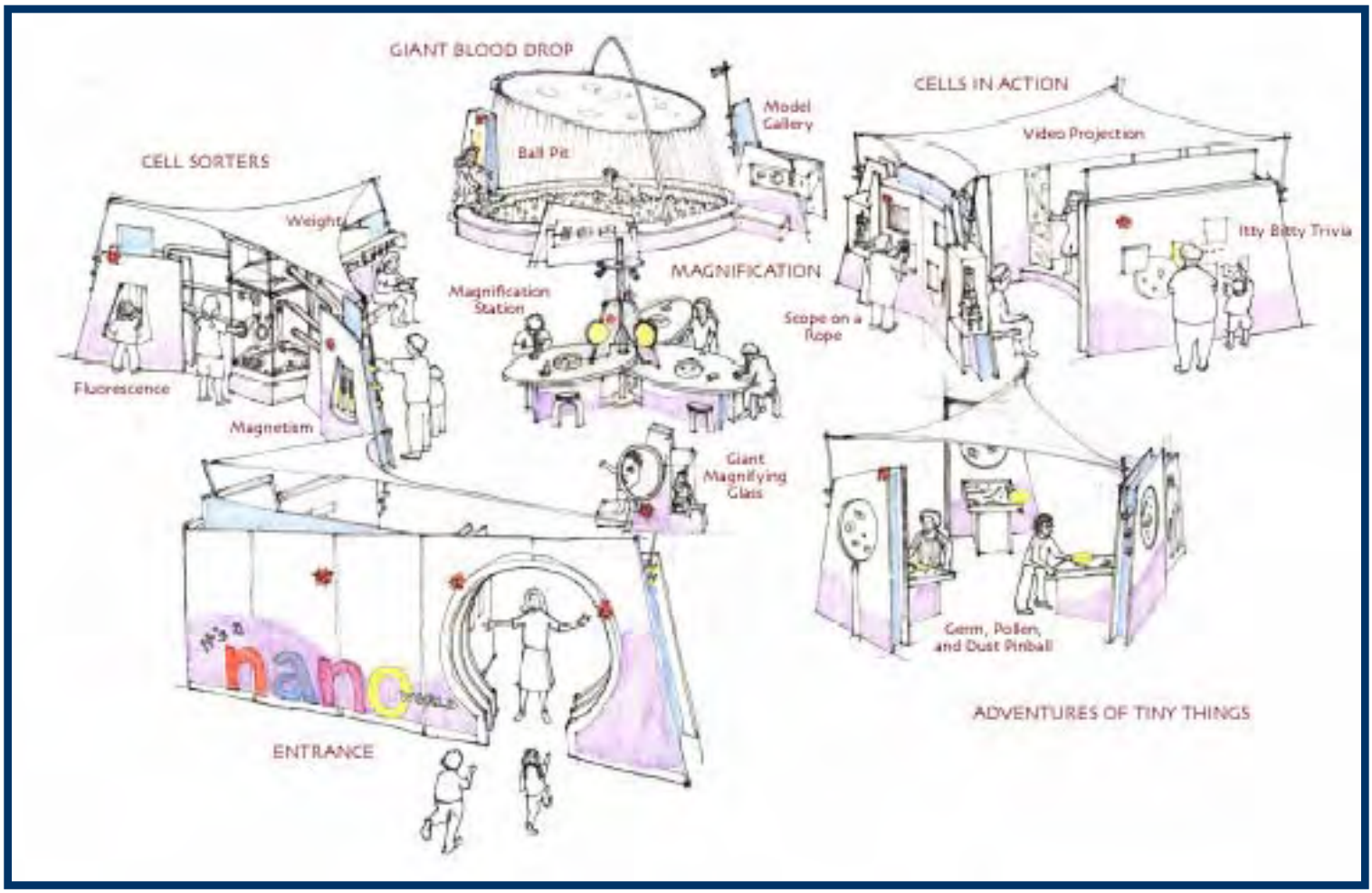
Scientists work in rooms
that have to be clean.
One piece of dust
clogs a nano machine.

It's a Nano World

Smaller Than a Spot on a Ladybug

Primer for Innoventions at Epcot® Staff

IT'S A NANO WORLD TUTORIAL



WHAT IS NANOBIOTECHNOLOGY?

Nanobiotechnology: Building innovative tools to study biology at the nanometer scale.

Nanobiotechnology is a big word made up of three parts:

- NANO is really, really tiny
- BIO is living things, and
- TECHNOLOGY is about tools.

All together it means making and using very tiny tools to learn about living things.

OVERVIEW OF EXHIBITS

Walk through the **Gateway** of the Nano World and begin to explore biology at a scale smaller than anything you can see with the naked eye. See how nanotechnology is being applied to understand the fundamentals of life. Peer through **Giant Magnifying Glasses** that enlarge everyday objects. Explore at the **Magnification Station** and look into the Nano World of things around us. Learn in **Adventures of Tiny Things** how germs and dust affect our everyday lives—they make us sick, they make us sneeze. Enter the **Cells in Action** and step into bacteria enlarged millions of times in size. See how technology has advanced to allow us to create devices that are as small as these germs. Then be surrounded by millions of blood cells as you jump into the **Giant Blood Drop**. Get a hands-on experience as you use technology to sort cells in the **Cell Sorter**. You will experience how technology is being used to study biology at the microscopic and submicroscopic scale. Venture into the Nano World to discover how we can build innovative tools to study biology at the nanometer scale.

THE EXHIBITS

Entrance

***Fun fact**. If you stack three silicon atoms one on top of another their height is approximately 1 nanometer. Computer chips are made of silicon.*

The entrance to **It's a Nano World** is a portal to the nano world. Around the outer rim of the entry way are images of animals and plants, while on the inner rim are images of cells. On one side of the entrance is 'How many nanometers am I?' where children can measure their height in nanometers. There are one billion (1,000,000,000) nanometers in a meter, which is 39 inches.

Giant magnifying glass

The giant magnifying glass magnifies approximately 3-4 times. It is made from a Fresnel lens. The Fresnel lens is named for its inventor, French physicist Augustin Jean Fresnel. Fresnel studied light and optics in the 19th century. It was originally developed to help project the light from lighthouses.

Look Closer

Look Closer features highly magnified photographs of familiar objects such as a penny, a q-tip, a flower, a bee. Each photograph has decreasing levels of magnification until an easily recognizable photo of the item is revealed.

Scale Gallery

This interactive collage features microscopic objects including a red blood cell, white blood cell, nerve cell, skin cell, germs (bacteria and viruses), DNA, and computer chips 10,000 times bigger than life size. Visitors can flip each picture to read a description of the object.

Pinball machines

Each of the pinball machines represents a different story about a micro-scale object: germs, dust and pollen.

Germ Launcher

> ***Fun fact.*** *The largest known bacteria is Thiomargarita namibiensus, a single cell is so big it can be seen with the naked eye.*

The germ launcher portrays the transfer of germs and the effects that they have on people. Germs include viruses and bacteria.

Dust Tippy Table

The dust tippy table follows the travels of dust from its sources to different places. Dust can make us sneeze. In addition dust can destroy a computer by 'short circuiting' the tiny wires inside of a computer chip. Dust ranges in size from less than a micrometer to over 30 micrometers. The average wire in a computer chip is 1/10 of a micrometer or about 1/1000 the width of a hair.

> ***Fun fact.*** *Dust is so small it can be carried almost half-way around the world by the wind. Dust from Mongolia has been detected as far away as Arizona.*

Pollen Pinball

The pollen pinball portrays the role of pollen in fertilizing flowers and also why we sometimes sneeze when we inhale pollen. Pollen is approximately 10-100 micrometers in size; smaller pollen is produced by plants that rely on wind to carry it to other plants.

Theatre

This theater environment places visitors in the midst of a world of living moving cells and shows how scientists make tools to study them. Two videos, *Cells in Motion* and *Tiny Tools* play one after the other.

> ***Fun fact.*** *About one billion (1,000,000,000) bacteria would fit on the head of a pin.*

Cells in Motion is a series of images that show cells including those found in the human body and bacteria. One segment shows the flow of blood cells through a vein.

Tiny Tools is a video that portrays the process scientists use to create tools to study small living things. The action takes place in a clean room, a laboratory with heavily filtered air to reduce dust and other particles. Scientists dress in 'bunny suits' (formally known as 'togs') to protect the tools that they are building from these particles. At the end of the video are images of nerve cells that are growing on microfabricated structures. Scientists build these tiny structures to study the growth and behavior of cells in order to understand how they function.

Fun fact. *Inside of the average computer are tiny wires that are about 1/1000 the width of a hair. Scientists are now working on wires that are maybe 100 atoms wide.*

Ball sorters

Two ball sorters demonstrate the basic principle of how scientists use machines to separate cells. In the exhibit's cell sorters, the cells are represented by wooden balls. Cells are marked to make them either fluorescent or magnetic. The cells are then flowed through a chamber where either the fluorescence or magnetic properties are determined. Cells that are either fluorescent or magnetic are then picked up using the vacuum tubes and collected in individual hoppers.

Real cell sorters do not sort cells one at a time and there is no manual intervention. The cells are flowed in a very narrow stream, and their fluorescence is measured with a laser.

Scientist sort cells to study the different types of cells that might be in a sample of blood. For example blood can be separated into red and white blood cells. Red blood cells carry oxygen, and white blood cells fight germs.

Blood drop

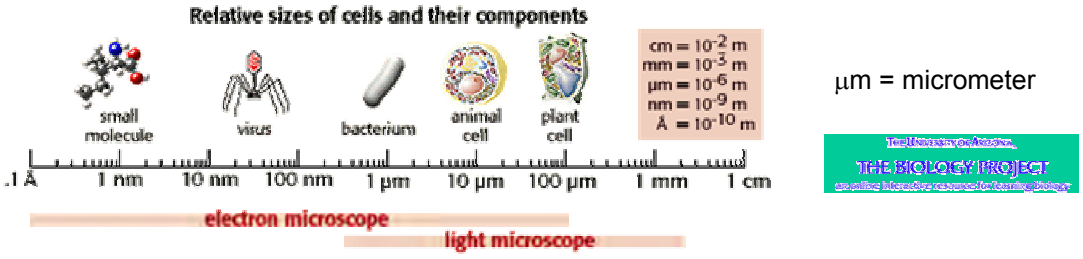
The blood drop demonstrates size and scale in a biological context. In the exhibit, the blood cells are represented by red plastic balls, and there are approximately 3,500 in the pit. There are a few white blood cells, showing that blood has less than 0.1% white cells. The entire pit itself is scaled 10,000 times so that it is size of a drop relative to the blood cells.

Real blood cells are approximately 10 micrometers. If you were to take 10 blood cells and lay them end to end they would be approximately 100 micrometers, or the width of a hair.

Powers of ten

The video loop 'Powers of Ten' was created by Ray and Charles Eames. It takes the visitor from view of the Earth that is 100 million meters (10^8 meters=500 million miles) down to a region of DNA that is on the angstrom scale. (An angstrom is ten times smaller than a nanometer!)

The video starts off with a view of the Earth, then zooms into the hand of a person laying on a blanket in a park in the city of Chicago. The video continues to zoom in on a cell at the 10 micrometer size scale. Next is an image of the double helix of DNA which appears at the 100 nanometer (1000 angstrom) scale. From there the video zooms into the atomic structure of DNA and ends at the 1 nanometer (10 angstrom) size scale.



µm = micrometer

Magnification station

The table at the *Magnification Station* has a collection of lenses that magnify objects from 2-5 times. Lenses magnify objects by bending the light and making the objects appear bigger. Lenses have different focal lengths, which determines how far the lens must be from the object to be in focus.

On the front panel of the ***Theatre*** are two 'Scope on a Rope' magnification tools. The scope on a rope is connected to two video displays. One scope on a rope magnifies an object 20 times, while the other magnifies an object 300 times. These tools have a very small 'focal length' so they need to be held tight against the object that you are trying to magnify.

The Evaluators

The evaluation was conducted by Edu, Inc, a full service evaluation firm located in Fort Myers, FL and Ithaca, NY. An outgrowth of research at Cornell University, Edu has participated in evaluation of over thirty NSF-funded projects since 1993.

Experience includes projects for Harvard, Cornell, the University of California, the Annenberg Foundation, and the US Departments of Education and Commerce.