NISE network™
NANOSCALE INFORMAL SCIENCE EDUCATION

Visitor's Drawings of *Small*

Front-End Evaluation

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Purpose

This report documents a study conducted at the Exploratorium to characterize how visitors depict the concept of *small*. Working on the premise that people, both experts and novices, "start with a rich pool of representational competence" (diSessa, 2004) , this study looks at visitors' drawings in order to inform the design of diagrams, animations and other visualizations that help the public visualize and learn about the nanoscale in informal learning environments. This work was conducted as part of the Visualization Laboratory, under the larger NISE Net effort.

Summary Of Key Findings

Table 1 summarizes the key findings from this study and their possible implications for the design of visualizations.

Table 1. Key findings and their implications

Finding		Implication
About a quarter of the drawings included a small pencil mark, or dot, that was used to convey *small,* either in a comparison or simply to note that the *small* is invisible	→	Objects that are on the border between the visible and invisible could be useful in introducing the world of the very small. Try using objects that are barely visible as size references in visualizations for the nanoscale.
About 15% of the visitors tried to depict the actual size of the smallest object they could imagine.	→	Consider including actual size objects in visualizations to establish size and scale.
Visitors used macroscale objects in their analogies to convey the magnitude of the size differences between familiar objects and the very small.	→	Experiment with analogies that use familiar macroscale objects to help visitors visualize the magnitude of the size difference between the nanoscale and other size scales.
About 10% of the visitors used numbers somewhere in their drawings.	→	Support visitors in interpreting numbers in diagrams.
Less than 10% of the drawings included the human body. The human was mainly used in zooms, as the largest object in a sequence of smaller and smaller objects.	→	The human is too big of an object to serve as the main size reference to convey how very small something is. Consider using smaller, but familiar, objects as references.

Additional findings and more detailed explications can be found in the Results Section of this document, organized according to the different types of representations visitors drew to convey *small.*

Method

The data for this study were collected as part of a pre-test administered in a series of evaluation studies on the scale ladder diagram. The pre-test tasks and questions were the same in all these studies as was our recruitment method.

That is, we systematically recruited visitors inside the Exploratorium, asking every 3rd visitor who crossed an imaginary line for an interview. We did not approach visitors under the age of 10, as identified by sight. If it were not clear if the visitor who crossed our line was 10 or older, the evaluator would ask the child's age before the interview. We conducted interviews with individual visitors, although other members of their visiting group were welcomed to listen in if they chose.

At the start of the interview, we asked visitors to name the smallest thing they could think of and to describe both verbally and with a drawing how they would communicate how small that object is. Earlier pilot testing indicated that some visitors would focus on drawing the object itself instead of trying to depict its size. When the evaluator felt that this was happening, she asked the visitor how his/her drawing would show someone, who did not know anything about that object, how small the object is. This was enough to redirect the visitor. In addition, the evaluator noted any explanations visitors gave for their drawing.

Data

We recruited and interviewed visitors on the following days:

6/24/2007	Sunday
7/1/2007	Sunday
7/8/2007	Sunday
7/10/2007	Tuesday
7/12/2007	Thursday
7/13/2007	Friday
7/15/2007	Sunday
7/17/2007	Tuesday
7/20/2007	Friday
7/22/2007	Sunday

In total, 121 visitors completed the drawing task ($N = 121$). Their demographic information are summarized in Table 2 and Table 3.

Table 2. Gender of visitors

Gender	Count
Female	65 (54%)
Male	56 (46%)
All	121 (100%)

Table 3. Age group of visitors

Age Group	Count
Child (10-12)	10 (8%)
Teen (13-17)	27 (22%)
Adult (18-65)	77 (64%)
Senior (65+)	7 (6%)
All	121 (100%)

Results

Visitors' Representation Types

Small is inherently a relational term that indicates a size comparison between one object and another. There are, however, different definitions of *small* depending on the frame of reference and the nature of the comparison.[1] To characterize visitors' descriptions of small in our drawing task, we iteratively developed a coding scheme by looking through visitors' drawings and descriptions, paying particular attention to the types of comparisons depicted. The following defines the categories we used and gives examples to better illustrate each category.

[1] For example, in their work with very young children, Ebeling and Gelman (1994) defined three meanings: 1) normative, where the object is compared to the typical size of its kind; 2) perceptual, where the object is compared to another object that is physically present; and 3) functional, where the object is assessed according to its intended use.

- Object-to-object comparisons. These drawings compare two or more object types to express relative size. Oftentimes, words rather than any graphical elements are used to indicate that one object is smaller than the other. Sometimes one of the objects, typically the smaller object, is described through annotations but not drawn. Figure 1 gives an example of a drawing that we placed in this category.

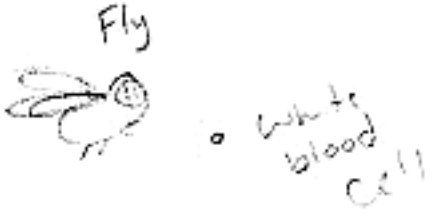

Figure 1.

Visitor drawing (V42) depicting how small a white blood cell is by comparing it to a fly.

- Actual Size– A few visitors tried to draw the actual size of the smallest object they could think of. When the visitors identified something in the macroscale as their smallest object, they drew that object. Figure 2 shows an example.

Figure 2.

Visitor drawing (V51) depicting how small a flea is. The visitor described small by drawing the actual size of the smallest object they could think of.

However, when they identified something invisible as the smallest thing they could think of, these visitors did not draw anything, instead explaining that it would be impossible to draw anything to communicate how small that object is. For example,

> Visitor24: Can't see, can't draw it. I can't even see it. So I can't draw it.

- Analogies. These drawings convey size relationships by comparing the size difference between a pair of objects, the target, and another pair of more familiar objects, the base. They are in the form: *a is smaller than b as x is smaller than y*. One of the objects in the analogy may not be drawn but simply spoken. An analogy is shown in Figure 3.

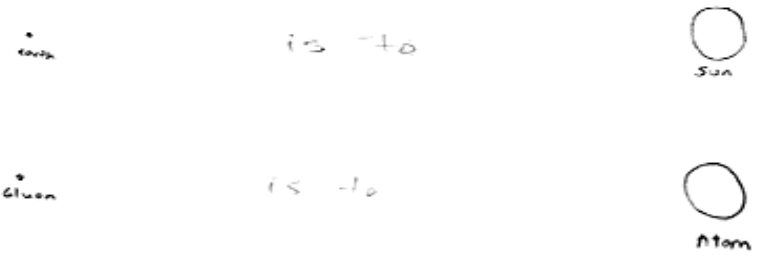

Figure 3.

Visitor drawing (V46) depicting how small a gluon is through the analogy, earth:sun :: gluon:atom.

- Notation – This category includes drawings in which visitors use a lone mark to represent the object. The mark is very small, often just a dot, and stands for something in the invisible world. See Figure 4.

Figure 4.

Visitor drawing (V250) depicting how small an atom is. A small mark is used to describe how small the atom is. The visitor mentions, "It's so small you can't see it."

- Zooms. A zoom is similar to an object-to-object comparison; however, the drawing uses graphical elements to show magnification; that is, the smaller object is part of another, larger object. So, in addition to depicting size relationships, a zoom describes containment relationships between the different objects included. See the example in Figure 5.

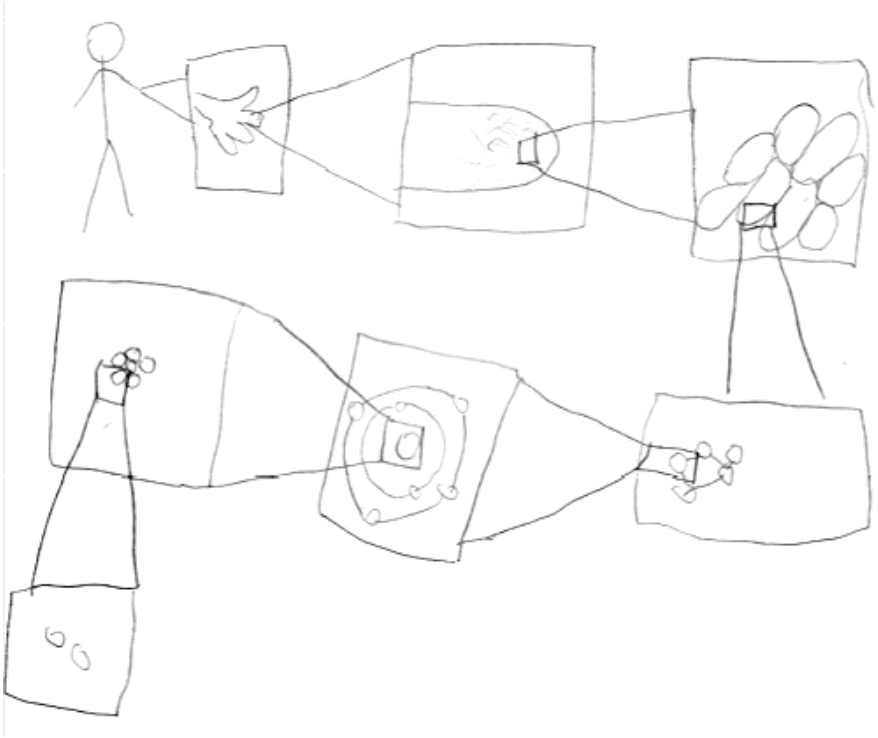

Figure 5.

Visitor drawing (V120) depicting how small a quark is by zooming in on a human being.

- Technology – These drawings depict the type of device that would be necessary to see the *small*. So, something is small because we require special equipment to see it compared to simply using our unaided eyes. See Figure 6 for an example.

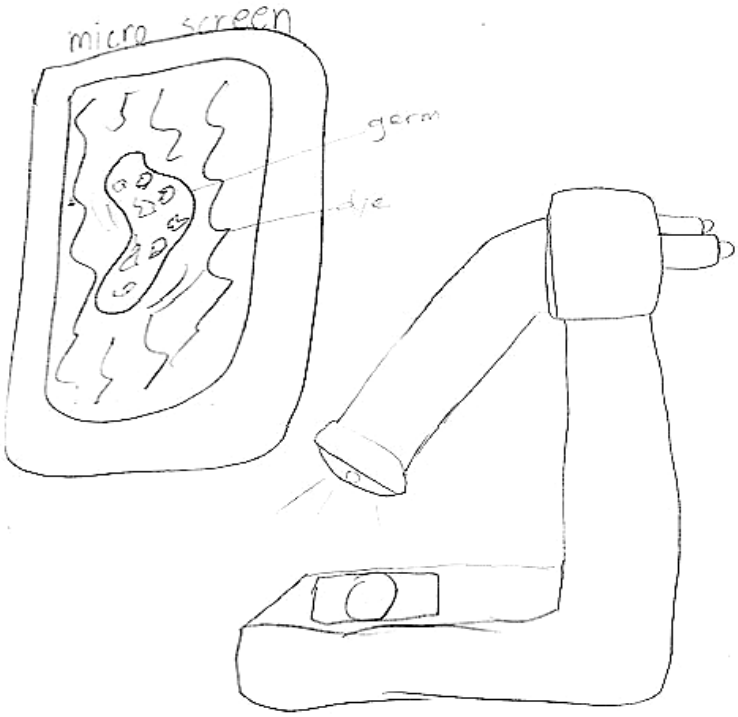

Figure 6.

Visitor drawing (V3) depicting how small a germ is. The visitor drew a microscope that would be required to see the smallest thing she could think of.

- Others – There were only 2 drawings that did not fit any of the categories above.
  - Behavior. One visitor described small by depicting its unique properties and behaviors, which are different compared to other objects' behaviors. See Figure 7.

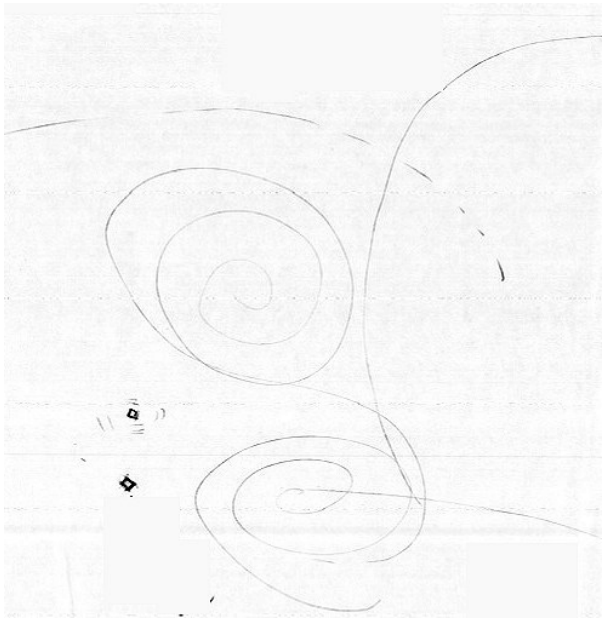

Figure 7.

Visitor drawing (V56) depicting how small a quark is. This visitor described small according to what the quark does (vibrate) and the physical residues (trails) it leaves.

  - Measure. One visitor gave the measured size. See Figure 8.

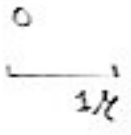

Figure 8.

Visitor drawing (V53) depicting how small a bacterium is by giving a numeric value of size.

Table 4 gives the count of the different types of visitors' representations of *small*. The following sections describe in more detail each of the representation types visitors used to express *small* and discuss possible implications for the design of visualizations to help visitors 'see' the nanoscale.

Table 4. Tally of the types of representations visitors drew

Representation Type	Count (out of 121)
Object-To-Object Comparison	48 (40%)
Actual Size	21 (17%)
Analogy	20 (17%)
Notation	15 (12%)
Zoom	10 (8%)
Technology	5 (4%)
Other	2 (2%)

Object-to-Object Comparisons

Approximately 40% of the visitors we interviewed chose to depict how small their smallest object is by comparing it to another, larger object or set of objects. We list the objects visitors used in their descriptions in Table 5 and Table 6 to catalog objects we can use in our own visualizations that similarly juxtapose different types of objects to communicate size and scale (e.g., scale ladder diagrams and perspective illustrations). These lists complement prior work (Tretter, Jones, Andre, Negishi, & Minogue, 2006 and Tretter, Jones, & Minogue, 2006), which identified anchors and landmarks that ground visitors' understanding of size and scale.

Table 5. The larger objects visitors used in visitors' object-to-object comparisons. We grouped the objects according to their actual size scale.

Macroscale			Microscale	Nanoscale	Atomic Scale	Subatomic Scale
m	cm	mm				
Person (1)	Penny (2)	Dot (14)	Cell (5)	Molecule (2)	Atom (2)	Electron (5)
	Bean (1)	Needle Tip (2)	Chip (1)	Nano (1)		Nucleus (1)
	Box (1)	Pin (2)	Hair (1)			
	Circle (1)	Ant (1)	Hemotoid (1)			
	Fly (1)	Eyelash (1)				
	Hand (1)	Flea (1)				
	Inch (1)	Sand (1)				
	Line (1)	Tick (1)				
	Finger (1)					
	Teaspoon (1)					

Table 6. The smallest object visitors could think of (Object-to-object comparison). Objects are grouped according to their actual size scale.

Macroscale			Microscale	Nanoscale	Atomic Scale	Subatomic Scale
m	cm	mm				
		Grain of Sand (1)	Cell (6)	Molecule (2)	Atom (16)	Electron (4)
			Amoeba (2)	Fluorescence Molecule (1)		Quark (4)
			Animal Cell (1)	Line Width Of A Silicon Circuit (1)		Photon (2)
			Bacteria (1)	Particles Inside Sunscreen (1)		Subatomic Particle (2)
			Microbe (1)	Virus (1)		Positron (1)

We found that only one person (1/48 or 2%) compared his smallest object to a human. So, despite prior research that identified the human body as a common reference size, very few visitors used the human body in their object-to-object comparisons. This may be because trying to convey how *very* small something is, is more convincing when the comparison is made to something else that is also very small.

It is also possible that because most visitors identified objects many orders of magnitude smaller than a human body, the human becomes a less relevant size reference in these

smaller worlds and their depictions. In fact, we found that the most common size reference used was not even a real object. Instead, it was simply a very small pencil mark or dot, which was used in the comparison to show that their smallest object is much smaller than what is visible. This implies that one way of helping visitors get a sense of the size of the very small is to include an actual size depiction of something that is small and nearly invisible.

A few (8) visitors (17%) who used an object-to-object comparison indicated approximately *how much smaller* their smallest object is than the larger object, making guesses at the magnitude of the size difference. Otherwise, the magnitude of the size difference was not a component of these descriptions, and s*mall* in these representations is an expression of relative size only.

Actual Size

We found that a little over 15% of the visitors tried to depict the actual size of the smallest object they could imagine. Although it is not possible to depict the actual size of a nano-size object, these drawings suggest that actual size may be important for visitors in interpreting the representations we create. They may, in fact, give visitors a reference point for understanding the scale of the illustration or depiction. By extension, we may want to explore including actual size objects to establish size and scale in visualizations we design.

Analogy

Approximately 15% of the visitors we interviewed used an analogy to describe *small*. Unlike most of the object-to-object comparisons and zooms, these analogies tried to describe the *magnitude* of how small something is. These analogies do so by comparing the smallest object visitors could think of to a larger object *and* then comparing that pairing, which we call the target pair, to a more familiar object pair, called the base pair. Table 7 lists the analogies visitors used to visualize the size of the smallest thing they could name.

Table 7. Analogies visitors used to describe the smallest thing they can think of. The *base* is a set of familiar objects and relationships, and the *target* is a set of less familiar objects and relationships. Comparing the target to the base elicits the shared relationships between the two, in these cases, the scale of the size differences. Those analogies that are within 2 orders of magnitude in accuracy are in green; those within 4 are in orange, and those that are 5 or more orders of magnitude from accuracy are in purple. The example shaded gray could not be determined.

Base *A* is smaller than *B*	::	Target *X* is smaller than *Y* (*X* is the smallest object visitors named)
Earth : Sun	::	Gluon : Atom
Human Life Scale : Night Sky	::	Quark : Sand
Moon : Sun	::	Electron : Atom
Penny : Earth	::	Electron : Atom
Penny : Earth	::	Electron : Atom
Dot : Earth	::	Electron : Dot
Dot : Galaxy	::	Neuron : Dot
Dot : Room	::	Proton : Dot
Pencil : Football Field	::	Proton : Dot
Pin : Soccer Field	::	Proton : Golf Ball
Me : Bldg	::	Things In Atoms (Contains Quarks) : Atom
Tennis Ball : Football Field	::	Nucleus : Outside Of Atom
Object : Football Field	::	Atom : Bee
Dot : Earth	::	Atom : Dot
Dot : Earth	::	Atom : Dot
Dot : Empire State Building	::	Atom : Dot
Dot : Skyscraper	::	Atom : Dot
Sand : Room	::	Atom : Sand
Basketball Size : Earth	::	Atom : Tire
Man : Empire State Bldg	::	Nanoparticle : Needle
Building : Earth	::	Microorganism : Person

Table 7 shows that in all cases, visitors chose macroscale objects for the base pair, with a majority, 14 out of 20 (70%) visitors, using a base object that was larger than 100m in size. In fact, when we looked through all the representations visitors drew, we found that visitors used larger objects (i.e. > 10m) *only* in analogies, in order to convey the *magnitude* of the size differences without using numbers.

Only 7 out of 20 (35%) visitors came within 2 orders of magnitude in accuracy in their size comparisons. However, since people tend to be more facile at judging the size of large as opposed to small objects (Tretter, Jones, & Minogue, 2006), analogies that use familiar macroscale objects as the base may be a powerful way to help visitors visualize the magnitude of the size difference between objects in the nanoscale and more familiar objects.

Notation

When we looked through visitors' representations, we were surprised to find a few diagrams that consisted simply of a dot. Although some of these dots were intended to represent the actual size of something small in the macroscopic scale, others (15/121 or 12%) were clearly just marks to indicate *small*. Often, visitors used these dots as a placeholder for something invisible. This suggests that using objects in visualizations that are on the edge of being visible could be a helpful means of introducing the invisible world of the micro and nanoscale.

Zoom

Zooms, like object-to-object comparisons, describe relative size, but they also express containment relationships, in which the smaller object is part of a larger object that, in turn, is part of yet a larger object. Zooms are a common device used to help people visualize the very small, and a few (10/121) visitors drew zooms to try to convey the size of the smallest thing they could think of. Although the count is low (only 8% of all the visitors' depictions we collected), these drawings may, nonetheless, help us design zooms to communicate the nanoscale.

Table 8 lists the objects that were included in each of the ten zooms visitors drew. Like Table 5 and Table 6, this list gives us an idea of small objects that visitors may be familiar with, which can inform what we may want to include in our visualizations.

Table 8. Objects included in visitors' zooms. Blue indicates the starting, or largest, object of the zoom, and red indicates the last, or smallest, object of the zoom.

Macro	person foot things in foot	person hand skin	person hand finger	person hand finger fingertip	person hand fingertip	fingertip		water		
Micro	things in thing	cells cell	skin cells cell	vessel in tip blood cell	cells		bacteria cells cell nucleus			
Nano	mole-cule	mole-cule	protein mole-cule	mole-cule	mole-cule			mole-cule		
Atom-ic		atom	atom	atom	atom		atom	atom	atom	atom
Sub-atomic			electron	electron	nucleus quark	sub-atomic particle		neutron	 quark	proton quark

Zoom

We specifically looked to see what objects visitors chose to zoom in from. The largest, or the starting, object may be the reference point for understanding the size of the smaller, subsequent objects in the sequence. We found that 5 out of the 10 visitors, who drew a zoom, started with the human being. This suggests, that although the human is not a common size reference in other representation types, the human body may be more relevant in zooms. Yet, not all zooms need to begin with a depiction of a human being.

Six out of the 10 zooms included an object that is (likely) in the nanoscale[2], and in half of these drawings, a nanoscale object was included as an object between a known larger object and a known smaller object. Although most visitors' example of a nanoscale object was a molecule, the drawings suggest that zooms can be useful in introducing visitors to

[2] In this analysis, we put molecules in the nanoscale, even though some molecules can be microscopic in size.

the nanoscale as a size that exists between the familiar, larger scales and the smaller scales.

Like the object-to-object comparisons, the zooms that visitors drew predominantly showed *relative* size. But, unlike the other representations, zooms communicate composition and may, therefore, be useful for conveying other messages beyond size and scale.

Technology

A very small percentage of visitors (4%) drew the technology that would be necessary to see the very small. In all of these drawings, visitors depicted a microscope or a special lens, or portal, for viewing the very small. No one distinguished between the different technologies that would be needed to see the different size scales.

These drawings, though few (5 out of 121 or 4%), point to an additional way of orienting visitors to the nanoscale: Define size according to the type of equipment that would be needed to 'see' these worlds. Also, use graphical elements that indicate a shift in *how* we see the different scales of small. Unfortunately, we suspect that few lay people know about the different technologies that are needed to see the microscale versus the nanoscale versus the atomic and subatomic scales. So, cuing visitors to the size scale with the different technologies used to 'see' these worlds will not be straightforward.

A Look Across the Different Representations

In addition to looking at each type of representation, we looked across all the different descriptions visitors gave to convey *small* to see if there were more general patterns.

Doing so, we found that *small* was often associated with something invisible. That is, 33 out of 121 visitors (27%) used a dot or a very small mark, something that can be drawn but yet close to being invisible, to convey how small their smallest object is.[3] This suggests that the boundary between the visible and invisible world may partition what is small from what is not and be an important part of some people's understanding of size. This points to a potentially powerful way of helping visitors understand *small*: depict the actual size of macroscale objects that are barely visible with the naked eye; this object can then become the anchor, or size reference, for much smaller objects in the invisible world.

[3] These 33 include drawings from the object-to-object comparison and notation categories.

We also found that a small minority, 13 out of 121(11%) visitors, used numbers somewhere in their drawings and descriptions. This can reflect an unfamiliarity with measures at these small scales, which echoes earlier findings (Tretter, Jones, & Minogue, 2006). Although this does not preclude us from including numbers, it does mean that visitors may need support in interpreting numbers in visualizations of the very small.

Looking at all the drawings, we were surprised to find that very few visitors drew the human body although previous studies have found that to be a common size reference. The exception was the zoom, the only representation type that had multiple objects and steps. Yet, even there, only half the people started with the human body. So, perhaps in depicting the very small, the human is too big of an object to serve as the main size reference.

Concluding Thoughts and Next Steps

This study is an initial glimpse into the types of representations that visitors can invent to help them communicate and visualize *small*. The invented representations that were analyzed in this study were drawn in a very short time[4] as part of a longer interview on the Exploratorium floor. This study, therefore, does not provide a detailed look at the reasoning people use as they create and refine representations, and we hesitate to draw any conclusions about how visitors iteratively craft or carefully interpret visualizations about the very small.

Instead, this study gives us clues about visitors' first, quick attempts at conveying *small*. The findings are meant to suggest some potentially promising ways to create meaningful representations to visualize the very small based on visitors' initial takes. Further development and research can look specifically at the visualizations we design, as guided by these suggestions, to assess if and how they help the public 'see' the nanoscale.

[4] often under a minute

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