NISE network™
NANOSCALE INFORMAL SCIENCE EDUCATION

Visitors' Interpretations of Images of the Nanoscale

Front-End Evaluation

Joyce Ma

July 2008

Acknowledgements

The author would like to thank Karen Campbell, Nancy Carlisle, Karen Chang, Leah Johnson, and Emily Pinkowitz for recruiting visitors and administering the interviews for this study. Leah Johnson also helped in coding visitors' responses. The author would also like to acknowledge Rashmi Nanjundaswamy whose expertise guided the selection of the images used in this evaluation.

This report was based on work supported by the National Science Foundation under Grant No. ESI-0532536. Any opinions, findings, and conclusions or recommendations expressed in this report are those of the author and do not necessarily reflect the views of the Foundation.

Joyce Ma
Exploratorium
3601 Lyon Street
San Francisco
joycem at exploratorium dot edu
415 674-2874

Table of Contents

Purpose 4

Summary of Key Findings 4

Materials 5

Method 7

Data 7

Results 8

What visitors wanted to know about the image they were shown 8

What visitors recognized in the image 10

Estimating the size of the sample from the image 12

Interpreting color 16

Familiarity of scientific images of the nanoscale 17

Next Steps 17

Appendix A 18

Interview Questions 18

Purpose

Instruments such as the Scanning Tunneling Microscope (STM), Atomic Force Microscope (AFM) and Scanning Electron Microscope (SEM), allow scientist to visualize structures on the nanoscale that would not be visible otherwise. Although the images these instruments generate may potentially provide a powerful way of allowing the public to 'see' the nanoscale, little is presently known about how the public interpret these images or what types of supports they may need to help them understand what they see.

This front-end study was conducted with Exploratorium visitors to gauge the visiting public's interpretation of scientific images of the nanoscale. More specifically, it addresses the following questions:

- What do visitors want to know about these images?
- (How) do they determine the size of the objects in the images?
- What meaning, if any, do they assign to the false color used in the images?
- Have they seen similar types of images before?

The findings from this study can inform the type of accompanying interpretation we provide to help people make sense of scientific images generated with these instruments. This work was conducted by the Visualization Laboratory, as part of the larger NISE Net initiative.

Summary of Key Findings

- Not surprisingly, most (74%) of the visitors wanted to know what the image is of. To a lesser degree, visitors were also interested in how the subject fits into the larger world (e.g. where do you find it?), in the imaging technology that was used, and in the characteristics, or traits, of the sample (e.g. is it metallic?). These findings give us some initial ideas about the type of information we should provide to accompany an image to make that image more meaningful to visitors.
- Without any additional image information, visitors reported recognizing familiar objects in the image (63% of the visitors), and to a lesser extent talked about the shapes and patterns, the colors and the instruments they think were used to create the image. We speculate that this tendency to look for the familiar may lead to misinterpretations particularly when a nanoscale sample superficially resembles a more familiar macroscale object. This, in turn, may mean that such images require special attention in conveying what the image actually represents.
- Most visitors (72%) guessed that the subject of the STM, AFM or SEM was in the micro or smaller scale. However, visitors were more likely to think that the quantum corral (the STM image) is on the macroscale as compared to the other images. That is; the visiting public can have trouble estimating the size of the subject of these visualizations, even those that have become iconic in nanoscale science.

- Visitors used a number of clues to (mis)inform their size estimates of the subjects in these scientific images. Visitors based their guesses on: the accompanying size and scale information, the apparent similarity to a more familiar object, the possible instruments used to capture the image, and the shape and patterns they see.
- More (73%) visitors readily interpreted magnification (e.g. 20,000x) than size units such as nm (34%) or μm (10%). This suggests that noting magnification may be a more useful way of conveying size information than the scale bar that typically accompanies these images
- False color was assigned different meanings, the most common (34%) being temperature, even though color was never intended to denote temperature in any of the images. This suggests that color should be used with discretion, and selecting color maps requires careful consideration of the possible (mis)interpretations they foster. We may also need to inform visitors that the colors are artificial and provide them with guidance on how to read the false color that are applied.
- Most (73%) visitors reported never having seen images similar to the ones we showed them in this study, further underscoring the need for interpretative supports.

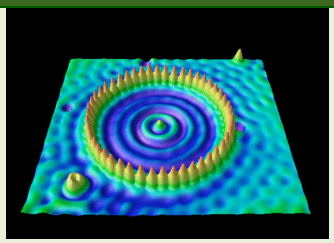
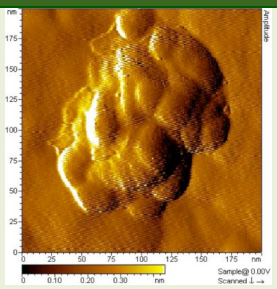
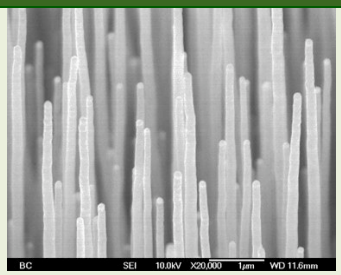
Materials

We chose three different images for this study in consultation with a material scientist who is familiar with nanoscale science and the different imaging technologies used. The three images were selected to represent a range of the types of scientific images of the nanoscale, according to:

- The type of instrument used since different instruments can produce images with very different looks.
- The subject featured. We chose subjects that would likely be included in the Visualization Laboratory's image database. This way, our findings could more directly inform the images we include in our collection.
- The quality of the image. We selected images for which we could discern details in an 8x10 enlargement.
- The notation for the size and scale of the subject. All the images were of nanoscale objects or structures, although different images used different ways of noting the sample's size.
- The colors used. Different color maps were used in different ways in the images selected and provided us with an opportunity to see how visitors interpret color's different applications.

Table 1 summarizes the images used in this study.

Table 1. Characteristics of the images used.

	STM image	AFM image	SEM image
Image			
Source	Don M. Eigler http://www.almaden.ibm.com/vis/stm/images/ring.tif retrieved July 12, 2008	Sun, W., Pan, S., & Wu, S. (2006). AFM Imaging of biological sample surfaces In Biophotonics, Nanophotonics and Metamaterials International Symposium. Oct. 2006, (pp. 179 – 182.)	www.nano-lab.com/stainlesssteel.html retrieved July 12, 2008.
Instrument	Scanning Tunneling Microscope (STM)	Atomic Force Microscope (AFM)	Scanning Electron Microscope (SEM)
Subject	Atoms (Iron atoms on copper in a quantum corral)	Influenza Virus	Carbon Nanotubes
Color	Color map - Hue-based, assigning single color to a particular height - Shading to indicate contour	Color map - Brightness-based scale denoting amplitude of AFM	Black and White
Size Notation	None	Grid with nm as units	1 μm scale bar at bottom of the image 20,000X indicating magnification

Method

An evaluator selected every third visitor who crossed a preset imaginary line on the floor and who appeared to be 10 years old or older. The evaluator asked the chosen individual for a short interview, unless that visitor was a minor. In that case we asked the accompanying adult for permission to talk with the youth first. If it were not clear how old a child was on sight, the evaluator would ask at the start of the interview. Each interview was conducted with individual visitors, although other members of the visiting group could listen in if they chose.

An interview lasted approximately 10 minutes. We showed only one image during each interview to avoid visitor fatigue, rotating between the three images. There was a set of questions common across the three images, and there were some questions that applied to only a subset of the three. For example, questions about false color were asked only for the STM and AFM images. The interview questions can be found in Appendix A.

Data

In all we completed 90 interviews (N = 90) that were administered during the following days:

April 13, 2008	Sunday	May 30, 2008	Friday
April 25, 2008	Friday	June 28, 2008	Saturday
May 1, 2008	Thursday	July 2, 2008	Wednesday
May 3, 2008	Saturday	July 5, 2008	Saturday
May 20, 2008	Tuesday	July 6, 2008	Sunday

The demographic information is summarized in Table 2 and Table 3.

Table 2. Gender of visitors

Gender	STM Out of 29	AFM Out of 30	SEM Out of 31	Total Out of 90
Female	13 (45%)	15 (50%)	20 (65%)	48 (53%)
Male	16 (55%)	15 (50%)	11 (35%)	42 (47%)

Table 3. Age group of visitors

Age Group	STM Out of 29	AFM Out of 30	SEM Out of 31	Total Out of 90
Child (10-12)	2 (7%)	5 (17%)	2 (6%)	9 (10%)
Teen (13-17)	9 (31%)	9 (30%)	7 (23%)	25 (28%)
Adult	18 (62%)	16 (53%)	22 (71%)	56 (62%)

Results

What visitors wanted to know about the image they were shown

Most (74%) of the *visitors wanted to know what the image is of*. A smaller percentage were also interested in:

- the larger context (i.e., the object's place in the larger world or its history) (26%)
- the imaging method (24%)
- the object's properties (22%)
- the colors used in the image (21%), and
- the size of the object (18%).

See Table 4 for examples and for a breakdown according to the three different images visitors saw.

Table 4. Types of questions visitors asked about the nanoscale images

Type of question	STM Out of 29	AFM Out of 30	SEM Out of 31	Total Out of 90
What is it? For example, Visitor51-STM: What am I looking at? Visitor59-AFM: What is it? Visitor85-SEM: What is it?	15 (52%)	24 (80%)	28 (90%)	67 (74%)
What is the larger context? How do the image and its subject fit into the larger scheme of things? For example, Visitor58-STM: What was it for? Visitor7-AFM: Is it part of the inside of the body? Visitor30-SEM: Where it comes from? What is its purpose?	7 (24%)	8 (27%)	8 (26%)	23 (26%)
How was the image made? For example, Visitor4-STM: How was it taken? Visitor48-AFM: Is this photographed through a microscope? Visitor56-SEM: so this is an SEM image (I come from an engineering background).. So, how they take pictures of small things?	10 (34%)	4 (13%)	8 (26%)	22 (24%)
What are the object's traits or properties? For example, Visitor63-STM: Either if it's hot or cold? Visitor23-AFM: Is it alive? Visitor36-SEM: Is it translucent?	5 (17%)	8 (27%)	7 (23%)	20 (22%)
Why those colors? For example, Visitor78-STM: What makes it funny colored? Visitor55-AFM: Is it the real color? Visitor9-SEM: Why is it in black and white? Does it have any pigmentation?	5 (17%)	7 (23%)	7 (23%)	19 (21%)
What is its size or magnification? For example, Visitor44-STM: what size is it actually? Visitor19-AFM: How small is it? Visitor6-SEM: Is this microscopic or macroscopic?	2 (7%)	7 (23%)	7 (23%)	16 (18%)
What do the numbers mean? For example, Visitor13-AFM: What do the numbers mean? What do the numbers relate to? Visitor53-SEM: What are the numbers at the bottom representing?	N/A	6 (20%)	1 (3%)	7 out of 60 (16%)
What does a specific part of the image mean? For example, Visitor2-STM: why is there a dimple (mid left purple) or why is there a crater on one of these big atoms? Visitor71-AFM: Why it has these bumps?	5 (17%)	1 (3%)	0 (0%)	6 (7%)
Nothing	2 (7%)	0 (0%)	0 (0%)	2 (2%)

- Implications for Image Interpretation: Our interpretative supports need to, foremost, identify the subject of the scientific visualization in a manner that is meaningful to the public. This can be challenging especially if the public is unfamiliar with the nanoscale. Some possibilities may be to include information that places the subject of the image in a larger context (e.g. what does the object do, what is it used for, where can we find it) and perhaps information about how the image was created and the sample's properties. We note, however, that less than 20% of the visitors were curious about size and scale.

What visitors recognized in the image

Overall, over half (63%) of the visitors we interviewed reported a resemblance between the sample and a familiar object.[1] See Table 5.

[1] But, there was a significant difference between the three images: Visitors were least likely to 'see' another object in the AFM image (of the influenza virus) than for the STM (of a quantum corral) and the SEM (of carbon nanotubes); χ^2 (2, N=89) = 9.06, p = .011<.05

Table 5. What visitors recognized in the image.

Visitors talked about...	STM Out of 29	AFM Out of 29	SEM Out of 31	Total Out of 89
Object Visitor29-STM: A volcano. [Points to upper right peak]: A mountain peak Visitor38-SEM: It looks like hair. Visitor59-AFM: It kind of looks like biology where you learn about it going from 2 cells to 4 cells to 8,	24 (83%)	13 (45%)	20 (65%)	57 (64%)
Nothing	2 (7%)	8 (28%)	5 (16%)	15 (17%)
Shape and pattern Visitor44-STM: circles, dimples, depressions. It has relief. Visitor31-AFM: Round shapes in it	3 (10%)	9 (31%)	1 (3%)	13 (15%)
Instrument Visitor3-STM: It looks like it was made on the computer. Visitor24-SEM: Magnified image because of shading Visitor54-AFM: I recognize that you're looking at something and it's, I would say, blown up because it looks kind of pixellated, like you're looking through a microscope	4 (14%)	3 (10%)	4 (13%)	11 (12%)
Size information Visitor45-SEM: It is some zoomed in image Visitor28-AFM: I think it's big	N/A	5 (17%)	2 (6%)	7 out of 60 (12%)
Colors Visitor4-STM: Orange is higher, blue is lower, green is middle. Visitor12-SEM: Part of it looks like highlighter marks Visitor61-AFM: I think it's right here [points to bright yellow part of image], or it's gotta be some kind of light. I don't know if it's the sun but it's some light.	5 (17%)	3 (10%)	2 (6%)	10 (11%)
Other Visitor6-SEM This may be showing gravity or force or centripetal force or magnetic force going in one direction.	0 (0%)	0 (0%)	3 (10%)	3 (3%)

- Implications for Interpretation: Images of nanoscale samples that superficially resemble more familiar (macroscale) objects may require additional interpretative supports to help visitors see past the surface similarity.

Estimating the size of the sample from the image

Most visitors (72%) guessed that the subject was something small, about as small or smaller than the width of a human hair.

Table 6. Visitors' guess at the approximate size of the object in the image. A few visitors could not decide between two, in which case, each of their two choices counted for half.

Visitors thought the subject was about the size of a ...		STM Out of 29	AFM Out of 30	SEM Out of 31	Total Out of 90
Macroscale	U.S.	0.5 (2%)	0 (0%)	0 (0%)	0.5 (1%)
	Mountains	5.5 (19%)	3 (10%)	0 (0%)	8.5 (9%)
	Football field	3 (10%)	2 (7%)	1 (3%)	6 (7%)
	Human size	2 (7%)	2 (7%)	0 (0%)	4 (4%)
	Ant	2 (7%)	0 (0%)	3 (10%)	5 (6%)
Smaller than macroscale	Width of hair	1 (3%)	0 (0%)	15 (48%)	16 (18%)
	Cell	5.5 (19%)	7.5 (25%)	6.5 (21%)	19.5 (22%)
	Virus	3 (10%)	9 (30%)	5.5 (18%)	17.5 (19%)
	Atom	6.5 (22%)	6.5 (22%)	0 (0%)	13 (14%)

When we compared visitors' responses across the three images, we found that *visitors were more likely to think that the quantum corral (the STM) was something in the macroscale* as opposed to something smaller[2]; χ^2 (2, N=90) = 8.06, p = .018<.05. About 30% thought that it was at least as large as a football field.

- Implications for Interpretation: Although there are many clues in an image to suggest the sample's size, even with the more iconic subjects, such as the quantum corral, visitors may have trouble guessing size and scale. The public needs support in interpreting the size and scale of the samples in scientific images of the nanoscale.

In fact, our data suggest that *visitors used a number of clues to help them estimate size of the object in an unfamiliar image*. See Table 7. No one factor seems to dominate.

[2] It is not clear why this would be. We note that of the three images only the STM did not have any size notation. However, preliminary findings from a subsequent study indicates that *even when we removed the size notation from the AFM and SEM images, visitors were better at guessing the size of the samples in the AFM and the SEM images*; χ^2 (2, N=88) = 16.2, p = .000<.05.

Size estimations for STM, AFM and SEM images without any size or scale information.

Visitors thought the subject was about the size of a …	STM Out of 29 with no scale or units	AFM Out of 26 with scale and units removed	SEM Out of 28 with scale and units removed
Macroscale	13 (45%)	2 (8%)	2 (7%)
Smaller than macroscale	16 (55%)	24 (92%)	26 (93%)

Table 7. What visitors based their size estimation on.

Visitors guessed the size of the object based on...	STM Out of 29	AFM Out of 29	SEM Out of 31	Total Out of 89
Numbers and Units– the accompanying numbers and units indicate the size. For example, Visitor 28-AFM: Because of nm, which means nautical miles. Visitor 6-SEM: The x20,000 says its magnified 20,000 times so this is an image from a high powered microscope.	N/A	9 (30%)	15 (48%)	24 out of 60 (40%)
Looks like ... – the image looks like an object of that size. For example, Visitor 1-STM: They (yellow circular peaks) are steep and have points [like a mountain] [Visitor guess the size of a mountain] Visitor 54-AFM: because it looks like bacteria that's multiplying Visitor 15-SEM: Cause some hair is long, some short [visitor guessed it was the size of a width of hair]	8 (28%)	7 (23%)	8 (26%)	23 (26%)
Instrument – The image seems to have been made with a particular instrument, like a microscope, that connotes a certain size. For example, Visitor 44-STM: It is surreal looking and electron microscope images look surreal and other worldly Visitor 55-AFM: It looks like it's under a microscope, Visitor 24-SEM: Looks magnified already	4 (14%)	9 (30%)	7 (23%)	20 (22%)
Shape and pattern – the shapes and patterns suggest something about the size of the object. For example, Visitor 81-STM: The fact that it's so perfect [She pointed to the circle of peaks.] A larger something wouldn't be so perfect and even. Visitor 7AFM: When I think of atom, I think of bubbly shaped. Visitor 73-SEM: It looks very complex, lots of strings.	4 (14%)	6 (20%)	6 (19%)	16 (18%)
Prior Knowledge – visitors are familiar with the image and the size of its subject. For example, Visitor 14-STM: I've seen on TV or a show, it reminds me of something scientific Visitor 25-AFM: It's like the images I've seen it school, it looks like one of them.	3 (10%)	4 (13%)	1 (3%)	8 (9%)
Unfamiliarity – because the image is so unfamiliar, it suggests something that they are unlikely to encounter in daily life and must be either very big or very small. For example, Visitor 4-STM: I've never seen anything large like it before Visitor 31-AFM: Because I haven't seen anything big that	4 (14%)	1 (3%)	0 (0%)	5 (6%)

looks like this.				
Other. For example, Visitor 66-STM: Just that I hope it is, I like big things. Visitor 40-AFM: looks like it (pointing at blob) is on something larger	3 (10%)	2 (7%)	0 (0%)	5 (6%)
Perspective – the angle of the image says something about its size. For example, Visitor 3-STM: looks like looking down Visitor 77-AFM: It looks like an explosion and the picture is taken from above	2 (7%)	1 (3%)	0 (0%)	3 (3%)
None – visitors cannot describe on what they based their guess.	7 (24%)	1 (3%)	2 (6%)	10 (11%)

- Implications for Interpretation: If possible, use other means of suggesting size beyond using units such as nm or μm, since visitors look at other aspects of the image to guess at size. For example, we may try to compare the size of the sample to a more familiar object, or indicate that special equipment was used to generate the image.

The SEM and the AFM image we used in this study had different ways for noting size and gave us our initial opportunity to gauge which notation may be more accessible to visitors. Whereas the AFM image used a grid to indicate the length and width in nanometers, the SEM used a scale bar and noted the magnification of the image. We found that when size information was included with the image, *more visitors readily interpreted magnification (e.g. 20,000x) than units such as nm or μm*. And, more visitors knew nm as nanometers than μm as microns or micrometers. See Table 8.

Table 8. Visitors' interpretations of size notation - units and magnification.

	AFM **Visitors' interpretation of nm** Out of 29	**SEM** **Visitors' interpretation of μm** Out of 30	**SEM** **Visitors' interpretation of x (times magnified)** Out of 30
Incorrect Interpretation	3 (10%)	3 (10%)	1 (3%)
No interpretation / or don't know meaning	16 (55%)	24 (80%)	7 (23%)
Correct Interpretation	10 (34%)	3 (10%)	22 (73%)

➢ Implications for Interpretation: Consider noting size using *x times* magnification rather than relying solely on a scale bar with nm or μm units

Interpreting color

Color was assigned different meanings, the most common being temperature. For the two images with false color (the STM and the AFM images), 34% (19/56) visitors thought the color represented temperature, though it was not used to denote that in either of the images. Otherwise, visitors thought the colors were used to indicate elevation or were used to indicate shadows on a three-dimensional surface under a light source. See Table 9 for a tally of the interpretations visitors gave for the false color used in the STM and the AFM images.

Table 9. What visitors thought the colors indicated.

The meaning visitors gave to the false color in the images	STM Out of 28	AFM Out of 28	Total Out of 56
Temperature – The colors indicate the temperature, whether a region is hot or cold. Visitor 63-STM: Hot or cold. Visitor 74-AFM: It looks like a temperature gradient, where white is hotter and it's cooler where darker.	12 (43%)	7 (25%)	19 (34%)
Elevation – The different colors indicates the elevation or height of the object. Visitor 57-STM: Where it's deeper, it's darker. Where it's lighter, it's higher [in relief]. Visitor 19-AFM: I think it's depth	7 (25%)	6 (21%)	13 (23%)
Light Source And Contours – Colors convey the light and shadow on a 3-dimensional surface under a light source Visitor 10-AFM: The darker areas are the shadows cast by the light.	0 (0%)	11 (39%)	11 (20%)
Object – The colors represent a particular object. Visitor 39-STM: Blue is oceans Visitor 7-AFM: These [dark portions] are the cancer parts and these [light portions] are the normal parts.	8 (29%)	3 (11%)	11 (20%)
Nothing – The colors do not signify anything.	3 (11%)	4 (14%)	7 (13%)
Other– The colors indicates a certain property (other than temperature or elevation) or trait of the sample. Visitor 44-STM: They describe density Visitor 48-AFM: The colors indicate that it's a living organism,	4 (14%)	3 (11%)	7 (13%)

➢ Implications for Interpretation: Be careful in using false color and in selecting a color map for images of the nanoscale since color can be interpreted in a variety of (unintended) ways, especially for an unfamiliar subject. When possible, provide

additional supports to help the public interpret the false color that are applied, which may first involve introducing the idea that color does not 'exist' at the nanoscale.

Familiarity of scientific images of the nanoscale

Scientific images of the nanoscale still are unfamiliar for a majority of our visiting public. Many (73%) of the visitors we interviewed reported never having seen anything like the image we showed them.

Table 10. Have visitors seen similar images before

Have visitors seen anything similar before?	STM Out of 28	AFM Out of 30	SEM Out of 31	Total Out of 89
No	23 (82%)	22 (73%)	20 (65%)	65 (73%)
Yes	5 (18%)	7 (23%)	7 (23%)	19 (21%)
Uncertain	0 (0%)	1 (3%)	4 (13%)	5 (6%)

Those who believed they had seen similar images before thought they had seen something like it in:

- School
- Their professional life
- Other science museums
- TV documentaries
- Science fiction and video games

➢ Implications for Use: Be careful when using unannotated images to represent the nanoscale. The public may not be familiar enough with such images to know what they are supposed to stand for.

Next Steps

This study was the first step in determining how the visiting public interprets scientific images of the nanoscale. It has brought up interesting findings, which we plan to pursue with more targeted evaluations. Specifically, we plan to look at the different ways of noting size and scale on these images to identify those that are meaningful to visitors and to experiment with different color maps to elicit guidelines for the use of color in these images. This set of studies should better inform our use of these types of scientific visualizations of the nanoscale for public interpretation.

Appendix A

Note that visitors' responses to questions 6-9 were not included in this document's analysis.

Interview Questions

So, here's the image. [Image. _____]

1. What, if anything, would you like to know about this image? [Note on copy of image] [Probe to exhaustion.]

2. I know that I'm not telling you much about it at this point, but what, if anything, do you recognize in this? [Anything else… to exhaustion.]

3. Can you make a guess as to how big or small that is? [Show back of clipboard.] So, is it about the size of

US	Human size	Cell
Mountains	Ant	Virus
Football field	Width of hair	Atom

4. Is there anything about this that made you guess that it is as small /big as a _____?

5. [If image has color] What do these different colors mean to you? If anything.

[If **STM**…] I'd like to tell you a little more about this image. This is taken with a special machine called a scanning tunneling microscope. This machine can detect individual atoms.

6. What comes to mind when you hear the word atom?

7. How would you describe to a person who's never heard about atoms, how small an atom is?

8. I know that I'm not giving you much information but can you guess what in this image shows an atom? [Note on copy of image.]

9. Is that surprising in any way? Is this how you expect an atom to look? [Probe for why surprising]

[If **has numbers**…]

10. What do these numbers mean to you if anything? [Note what numbers they refer to]

11. Just one last question. I promise. I was wondering if you've seen anything like this before?

    a. [If YES] Do you remember where?