Discover Earth: An Innovative Technology Program for Libraries and their Communities

Data Visualization Comparison Report
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Jessica Gonzalez and Kate Haley Goldman

BACKGROUND

The National Center for Interactive Learning (NCIL) at the Space Science Institute (SSI) was awarded a grant from NSF for it's *Discover Earth* (DE) project (NSF/Geo # 1034946). This research project was a part of NCIL's STAR Library Education Network (www.STARnetLibraries.org), also funded by NSF, which produced two traveling education exhibitions: *Discover Earth* and *Discover Tech*. The DE traveling exhibition used current geoscience research data to illustrate important Earth science concepts (e.g. spatial/temporal scales, cycles, states of matter). It also promotes the geosciences and geoscience careers as exciting and highly relevant to modern society. Technology is transforming not only how we conduct scientific research and education (both formal and informal) but it also has had a profound influence on the way people can communicate and access scientific information.

The purpose of this project was to develop, implement, and evaluate several geoscience education display technologies in a library setting to explore the benefits and drawbacks of each technology. Of specific interest was the comparison of global data visualizations on a Magic Planet (MP) and a Multitouch Table (MT). The MP is a desktop-sized globe approximately 18 inches in diameter, with a separate touch-screen control. The MT is a coffee table-sized (approximately 40 inches long) waist-height touch surface that can accommodate input from multiple points. (See Figure 2 for pictures of both devices). To study the relative affordances of the two displays, cued testing of library patrons was conducted to assess reactions to and comprehension of data visualization content and displayed narratives.

The main research questions under investigation are:

1. What differences do users perceive between the two display formats?
2. To what extent does the display format of the data visualization change user comprehension?
3. To what extent does the display format of the data visualization change user attention to specific components?

METHODOLOGY

Between February 22, 2013 and March 2, 2013 data was collected from library patrons who used both a Magic Planet and a Multitouch Table. Both devices presented the same global data visualization of ocean current flows and sea surface temperatures (http://svs.gsfc.nasa.gov/goto?3821) (see Figure 1), and were accompanied by the same text panels (see Figure 2 for complete display set-up, and Appendix for display panel text). However, they did differ in their user controls. The MT had a play/pause button for the data visualization, and a user could also move the visualization to a point earlier or later in time. The MP controls allowed a user to play/pause the data visualization, start/stop the rotation of the globe, and move the globe up/down and left/right. Semi-structured interview data was collected by one evaluator at Cherry Hills Library, a branch of the Albuquerque/Bernalillo County Libraries, in Albuquerque, New Mexico.

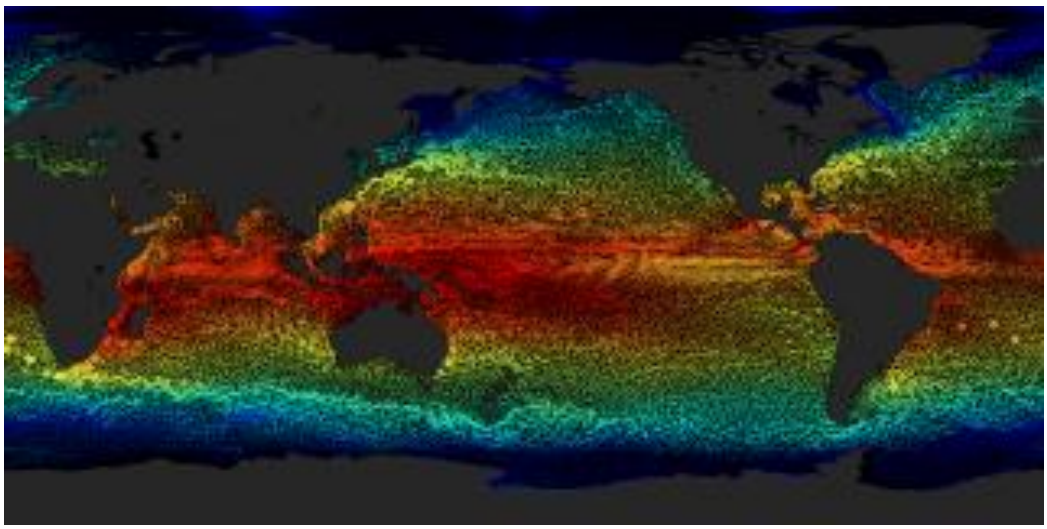

Figure 1: Global ocean flows with colors representing sea surface temperature (credit: NASA/Goddard Space Flight Center Scientific Visualization Studio)

Figure 2: Multitouch Table (left) and Magic Planet displays at Cherry Hills Library

Visitors who were at least 18 years old were eligible to participate in the study. In order to interview a representative cross-section of adults visiting the library, the researcher recruited participants using a continuous random sampling method by imagining a line at the entrance of the library and asking every second eligible visitor who crossed the line to participate in the research study. Once a visitor agreed, the researcher and participant walked over to the first multitouch device. All participants used both devices; order was counterbalanced to avoid any order-biasing effect. The researcher then started her stopwatch and timed how long the participant used the first device. When the visitor was finished interacting with the display, the researcher conducted the first part of the semi-structured interview. The researcher and participant then walked over to the other device and repeated the same pattern. The researcher timed how long the participant used the second device, and when the visitor was finished, the researcher completed the semi-structured interview. This concluded the visitor's participation in the study. Participants were then given a small gift to thank them for their time, a globe stress ball. The researcher then returned to the entrance to wait for the next eligible visitor to cross the imaginary line.

SAMPLE

Data was collected from 60 library patrons. By design, half viewed the MT display first; the other half viewed the MP display first. Sixty of the 141 individuals approached and invited to take part in the study agreed to participate, resulting in an acceptance rate of 42.9%.

Participants' ages (estimated from year of birth) ranged from 19 to 83, and the median age was 55 (n=58; 2 Ps declined to provide year of birth). Females made up 70% (n=42) of the sample, males made up 28.3% (n=17), and there was one participant (1.7%) who was of unknown gender.

There was some ethnic diversity in the sample, but the majority of participants self-identified as Non-Hispanic, White (66.7%, n=40) (see Table 1).

Table 1: Race/ethnicity

	n
White	66.7% (n=40)
Latino(a) or Hispanic	16.7% (n=10)
American Indian/Native Alaskan	6.7% (n=4)
Prefer not to answer	6.7% (n=4)
Asian / Asian American	1.7% (n=1)
Multiple ethnicities	1.7% (n=1)

Almost all of the participants had pursued higher education, and the majority had completed a Bachelor's degree or higher (see Table 2).

Table 2: Education

	n
High school or less	5% (n=3)
1-2 years of college or no degree	16.7% (n=10)
Associate's degree	5% (n=3)
Bachelor's degree	**45% (n=27)**
Graduate/professional degree	26.7% (n=16)
Prefer not to answer	1.7% (n=1)

The majority of participants had not seen a visualization presented on a sphere before (75%, n=45). The remainder indicated that they had seen one before (18.3%, n=11), or were not sure whether or not they had seen one before (6.7%, n=4).

FINDINGS

SUMMARY OF FINDINGS

- Participants felt that the MP device provided a more realistic representation of Earth, while the MT device was overall easier to understand/use.
- Participants displayed at least a partial understanding of the material presented in the MP and MT presentations.
- Given the amount of overlap in the information presented in the data visualizations and the text panels, it is unclear how well the MP and MT displays would be understood without text panels.
- Self-reported gain in learning was low, and possibily due to participants' prior familiarity with the topic.
- Participants were more likely to report additional learning when the MT followed the MP, but not from the opposite viewing order.

[Please note that answers to all open-ended interview questions may have been coded into more than one category.]

WHAT DIFFERENCES DO USERS PERCEIVE BETWEEN THE TWO DISPLAY FORMATS?

DIFFERENCES BETWEEN DISPLAYS

After viewing both the MP and MT data visualization displays, participants were asked to comment on what they thought was different about them. We were interested in particpants' perceived differences beyond the obvious format difference that the table was a flat, single-function, stationary, 2-dimensional display of a map, and that the sphere was a round, multi-function, rotating, 3-dimensional globe. Differences commonly mentioned by participants were image quality, data view, ease of use/understanding, and how realistic/accurate the data display was (see Table 3).

Table 3: Perceived differences between displays

(N=60)	MP	MT
Image quality* (n=27, 45%)	More detail/better image (n=11, 40.7%)	More detail/better image (n=21, 77.8%)
Data View* (n=23, 38.3%)	Able only to view specific areas at once (n=10, 43.5%)	Able to view entire image all at once (n=20, 87%)
Easy to use/understand (n=18, 30%)	Easier to understand/use (n=5, 27.8%)	Easier to understand/use (n=13, 72.2%)
Realistic/Accurate (n=12, 20%)	A more realistic/accurate representation of Earth (n=12, 100%)	-----

*Some Ps mentioned something different about both MP and MT within category

DISPLAY PREFERENCES

Participants also were asked to explain the ways in which the different displays were better for them (see Tables 4 and 5). They were asked to comment on the second display seen, and then on the first display seen. Among those who saw the MP second, the majority mentioned that it was a better/more accurate represention of Earth. Among those who viewed the MT second, the majority mentioned that the table had better image quality and was overall easier to understand/use.

Among those who saw the MP first, the most common answers were that nothing about the device was better, and that it provided a better/more accurate representation of Earth. Among those who saw the MT first, the most common answers were that nothing about the device was better, it provided the ability to see the entire image at once, and that it was overall easier to understand. Given that participants had good things to say about the two devices when asked about the second one used, it is likely that the higher number of responses indicating that nothing was better about the first device was the result of an order effect.

Table 4: Display preferences

	Second Visualization		First Visualization	
	MP (n=30)	MT (n=30)	MP (n=30)	MT (n=30)
Overall easier to understand/use	(n=11, 36.7%)	(n=16, 53.3%)	(n=1, 3.3%)	(n=9, 30%)
Better image quality	(n=7, 23.3%)	**(n=17, 56.7%)**	(n=2, 6.7%)	(n=6, 20%)
Better/more accurate representation of Earth	**(n=21, 70%)**	(n=3, 10%)	**(n=14, 46.7%)**	(n=1, 3.3%)
Ability to see image all at once	0	(n=13, 43.3%)	0	(n=10, 33.3%)
Ability to focus on specific areas	(n=6, 20%)	(n=1, 3.3%)	(n=6, 20%)	0
More interactive	(n=8, 26.7%)	(n=0)	(n=8, 26.7%)	0
Size	(n=1, 3.3%)	(n=1, 3.3%)	0	(n=1, 3.3%)
Nothing	(n=4, 13.2%)	(n=2, 6.7%)	(n=12, 40%)	**(n=11, 36.7%)**

Table 5: Sample comments: Display preferences

Second Visualization: MP	Second Visualization: MT
Overall easier to understand/use (n=11, 36.7%) • *Easier on my eyes. No glare. Animation seems better. The resolution is better. That I could see land mass better. I could see relation of tilt to direction of currents. That I could move it, quickly orient on specific area, and still see how it relates to whole earth. easier to imagine day and night on globe.* • *The 3D was better because it let you see the currents, easier to see the equator. 3D allows you to visualize better.* • *More interactive, easier to understand controls, more easily in my visual field, more interesting because it approximates reality. The currents stand out more.* • *It's more enjoyable to see as a planet than map. It's more a living Earth than flat map. It displays it much better. It draws you in more.*	Overall easier to understand/use (n=16, 53.3%) • *Yeah. I could easily figure out what I was looking at. I could more easily visualize this as a map of the Earth. I could see better the visualization of one big ocean.* • *It's easier. You can concentrate easier on this one, than the other one that is always moving.* • *Seeing it flat. It's more comfortable. The fact that it's flat helps me to see it better.* • *The whole picture, the movement patterns, I recognize much better on the table. Better idea of land masses, what they were, and where they were. And how they correlate with temperature of water.*
Better image quality (n=7, 23.3%) • *The colors weren't as prominent, so they weren't distracting. It's better to see 3D. Because your brain registers it faster and you get a better idea of bends/curves.* • *Yeah. The way the colors are mixed. Just gives more definition, more 3D. Makes you aware of things we don't know about earth. It's so vast, the ocean.* • *I could stop and focus on certain sections of earth. The colors were less distracting. The interactiveness.*	Better image quality (n=17, 56.7%) • *Yes. More clear distinction of where everything was at. The colors are more distinct. I can see the flows easier.* • *You get it all in at one glance. Crisper, easier on the eyes.* • *Continents were easier to identify. The colors are more clearly defined.* • *The brightness. The sharper details. Can see it all at one time. With globe you have to wait for it to turn around.*
Better/more accurate representation of Earth (n=21, 70%) • *A globe always gives you a better sense of what the Earth is really like. On a flat*	Better/more accurate representation of Earth (n=3, 10%) • *I could easily figure out what I was looking at. I could more easily visualize this as a*

presentation, you look at where you are. A globe lets you look more fully. Younger people would enjoy having more controls. • *It's more realistic. It shows how things are moving around, instead of a flat world. I like how it resets at the equator. I'm getting more out of this one. It's more like I could see myself watching this happen.* • *The scale is better on the globe. I like seeing the placement on the globe. It's more realistic.* • *I like a globe better, as far as seeing what it (the Earth) really looks like. Reminds us that we're on the globe. Being able to manipulate it the way you wanted.*	*map of the Earth. I could see better the visualization of one big ocean.*
Ability to see image all at once (n=0)	Ability to see image all at once (n=13, 43.3%) • *You can see the whole thing from one end to the other.* • *It wasn't moving, it's easier to focus on it. It's less distracting than having 2 motions at once on a globe. Colors seem brighter. Detail seems finer. Easier to understand whole picture at once on this [table].* • *The ease of seeing it all at once. It's flat and you can take it all in at once.*
Ability to focus on specific areas (n=6, 20%) • *More beautiful. More true to its form. It made me notice details of areas I might not have noticed on the flat one. Because I'm looking straight at one area instead of the whole picture.* • *I could stop and focus on certain sections of earth. The colors were less distracting. The interactiveness.*	Ability to focus on specific areas (n=1, 3.3%) • *The detail of current flow. The animation moves slower with possibly more pixels, so there's more detail in table. I like Mercator projection maps. I can move my body and get closer to a part of map.*
More interactive (n=8, 26.7%) • *I was able to move it around and play with it. I could see the N Pole and see temperatures there. It makes it more attractive.* • *How you can control the globe. So you can*	More interactive (n=0)

see the rotation of the earth and difference between hot and cold water surface movement.	
Size (n=1, 3.3%) • *A better sense of directionality of the water, perhaps because of smaller size*	Size (n=1, 3.3%) • *It was bigger and more clear. The globe is blurry and you can't get the full visual.*
Nothing (n=4, 13.2%) • *Not necessarily*	Nothing (n=2, 6.7%) • *No. It's old school. It's flat.*

First Visualization: MP	**First Visualization: MT**
Nothing (n=12, 40%) • *Don't think so.*	Nothing (n=11, 36.7%) • *No. they both pretty much get the point across.*
Better/more accurate representation of Earth (n=14, 46.7%) • *More accurate because it's a globe. You always lose scale when you flatten a map.* • *The idea that you could move it around and see different areas. A globe is better than a flat map because of size relationship.* • *I like globes to be in my house. You feel like you're looking at the real thing because the Earth is round.*	Better/more accurate representation of Earth (n=1, 3.3%) • *There's more surface to look at all at once so you get a different perspective of far reaching. Gives me more of a global view. I see it all in one.*
Overall easier to understand/use (n=1,3.3%) • *Shows you how the world is, so you can get a visual of different continents, where everything is. The screen worked better (was more responsive).*	Overall easier to understand/use (n=9, 30%) • *Easier to look at, easier to see. You can see it all in one visual field.* • *Easier to see land on table. The temperature was easier to see the colors were easier to see. More informative because you can see it all at once.* • *Because I could see it laid out simultaneously. More ability to orient myself to what I was looking at.*
Ability to see image all at once (n=0)	Ability to see image all at once (n=10,33.3%) • *The overall picture was there. On the globe you have to take it in piece by piece. I liked*

	how you could see it all laid out. It showed me the vastness of the ocean. • *There's more surface to look at all at once so you get a different perspective of far reaching. Gives me more of a global view. I see it all in one.* • *Tt gave me more of a real time feeling. I like it flat in front of you laid out at once. Instead of waiting for the globe to go around. Comparing one side to the other is easier than on globe.*
Better image quality (n=2, 6.7%) • *3D. More true representation of Earth. More interactive, you could see currents moving more clearer.*	Better image quality (n=6, 20%) • *Better able to visualize the continents. Just able to discern them better. Seemed to stand out clearer. The colors of everything and the movement.* • *The colors were better, crisper.*
More interactive (n=8,26.7%) • *I like the 3D, the interaction. The ability to change orientation of poles to see it from different angles. The color intensity.* • *I liked having the different controls. It was more fun to play with.*	More interactive (n=0)
Ability to focus on specific areas (n=6, 20%) • *It's cool that you can rotate it. To get the different views and seeing it from different angles.* • *I like how it's round. So it's easier to see N and S pole, and how everything is moving. I like how you could move it around and change the direction with the touch screen.*	Ability to focus on specific areas (n=0)
Size(n=0)	Size (n=1, 3.3%) • *It was larger*

THOUGHTS WHILE VIEWING DISPLAY

After viewing each data visualization display, participants were given a list of statements and asked to pick the one statement that most closely reflected their thoughts when viewing the visualization. No one statement was preferred by a majority of participants (see Table 6). Among participants who viewed the MP first, the most popular statement was "I learned or was reminded that the Earth is always changing and evolving"; among participants who viewed the MT first, the most popular statement was "It made me think about the complex interrelations in Earth Systems." Among participants who viewed the MP second, the most popular statement was "It helped me understand global processes";among participants who viewed the MT second, the most popular statements were "It helped me visualize specific events," and "It helped me understand global processes."

Table 6: Thoughts while viewing display

	Second Visualization		First Visualization	
	MP (n=30)	MT (n=30)	MP (n=30)	MT (n=30)
I appreciated how realistic the information appeared.	2 (6.7%)	1 (3.3%)	2 (6.7%)	5 (16.7%)
It helped me visualize specific events.	3 (10%)	4 (13.3%)	3 (10%)	**6 (20%)**
It helped me to visualize certain concepts of time and scale.	1 (3.3%)	1 (3.3%)	3 (10%)	3 (10%)
I learned or was reminded that the Earth is always changing and evolving.	**7 (23.3%)**	8 (26.7%)	3 (3.3%)	0
It made me think about the complex interrelations in Earth Systems.	6 (20%)	**10 (33.3%)**	3 (10%)	5 (16.7%)
I was amazed at the beauty of what was shown.	2 (6.7%)	1 (3.3%)	4 (13.3%)	0
It helped me understand global processes.	3 (10%)	1 (3.3%)	**5 (16.7%)**	**6 (20%)**
I felt a sense of the vastness of Earth.	0	0	3 (10%)	0
I felt a need to take better care of Earth.	0	0	1 (3.3%)	1 (3.3%)
It helped me better understand geography of Earth.	2 (6.7%)	1 (3.3%)	2 (6.7%)	2 (6.7%)
None of these options accurately reflect my thoughts.	4 (13.3%)	3 (10%)	1 (3.3%)	2 (6.7%)

TO WHAT EXTENT DOES THE DISPLAY FORMAT OF THE DATA VISUALIZATION CHANGE USER COMPREHENSION?

COMPREHENSION

The data visualizations conveyed information about the movement and temperature of sea surface currents, as well as information about the time frame during which the data was collected. The text panels which accompanied the data visualization displays each provided the same explanation about ocean currents, as well as an orientation to the data visualization. Participants were presented with each device and its accompanying text panel at the same time. Given the overlap of information between the text panels and the displays, it is not possible to tease apart whether any participant learning resulted from exposure to the data visualization display or the text panel. Most likely, it was a combination of both that resulted in any participant learning.

To measure comprehension, participants were asked what the data visualizations were about. The majority of participants displayed at least a partially correct understanding of the material presented. When participants were asked to explain what they thought the visualizations were about, most answers contained mention of sea currents/movement, and water temperature (See Tables 7 and 8).

Again, it is unclear whether this information was gleaned from reading the text panel, viewing the data visualization, or both. Also, it should be noted that most participants did not mention the time frame in which the data was collected, and when it was mentioned it was more likely to happen while viewing the MT.

Table 7: What is this visualization about?

	First Visualization		Second Visualization	
	MP (n=30)	**MT (n=30)**	**MP (n=30)**	**MT (n=30)**
Sea current/movement	**86.7% (n=26)**	**86.7% (n=26)**	**76.7% (n=23)**	**80% (n=24)**
Water temperature	83.3% (n=25)	70% (n=21)	73.3% (n=22)	70% (n=21)
Time frame	0	10% (n=3)	3.3% (n=1)	10% (n=3)
Same/similar to first visualization	---	---	63.3% (n=19)	53.3% (n=16)

Table 8: Sample comments: What is this visualization about?

First Visualization: MP (n=30)	First Visualization: MT (n=30)
Sea current/movement (n=26, 86.7%) • *The temperature of the ocean and the currents are moving that water around.* • *I guess it's about surface water temperature. Current flowing from hot part to cold part.* • *The different currents and what causes them, and the temperature.* • *The currents in the ocean. With the*	Sea Current/movement (n=26, 86.7%) • *About sea currents, and how they move on the earth's surface. And how they're interconnected. That's amazing to see.* • *Just showing how currents travel on either side of the equator. And how water heats up and moves, and influences weather* • *The circulation of water through the globe.* • *How the oceans are really connected. And*

temperatures. Low subcurrent is cool. Surface is warmer. How everything is connected. How it's all one big sea, basically. • *The ocean currents. Where they go. The temperatures.*	*how temperature (surface and deep water) affect our weather. Shows where currents are warm/colder. Shows movement of currents around the globe, carrying nutrients and heat, so it's important for all life.* • *The temperature across the oceans, the water currents/flows throughout the planet."*
Water temperature (n=25, 83.3%) • *About temperature around the globe, the water.* • *The ocean currents. Where hot ones are, where cold ones are. What global warming is going to do to us eventually.* • *The currents in the ocean. The temperatures also, color-coded.* • *The ocean currents and temperature displays. Different colors represent surface temperatures.* • *The temperature of water at different places."*	Water temperature (n=21, 70%) • *Looks like it's talking about temperature (of water). Blue being the coldest.* • *The ocean currents, and the red areas are warm, and the blue areas are cool. Just shows the flow of the ocean current.* • *About how temperature affects the movement of the water.* • *The Earth's currents of water, ocean. Which currents are warmer, which are colder.*
Time frame (n=0)	Time frame (n=3, 10%) • *Ocean temperatures from 2005-2006. you can see different flow patterns of currents around the globe at different latitudes.*

Second Visualization:MP (n=30)	**Second Visualization: MT (n=30)**
Same/similar to first visualization (n=19, 63.3%) • *About the same thing. Cold water is blue, circulates around the world, gets warmed, and rises to the surface and starts all over again.* • *Same thing. Temperature/current flow around Earth.* • *The same thing as the other. Currents and temperature of currents and how they affect continents.* • *The same as the other one. About currents in the ocean.*	Same/similar to first visualization (n=16, 53.3%) • *Same thing. Surface sea currents and water temperatures.* • *The same thing. Sea surface temperature.* • *The same thing. It has continents, oceans, and ocean currents.* • *The same exact thing as the other one. The temperature of water and how currents move for one year.*
Sea current/movement (n=23, 76.7%) • *Seeing the world's currents in 3D.*	Sea current/movement (n=24, 80%) • *The currents and temperatures of water*

• *It's about ocean currents again.* • *Rotation of the Earth. Movement of sea surface. How it's warmer at equator.* • *Currents of the ocean.* • *The surface currents, and oceans, and temperature. How they (temperature) affect the current.*	*mass on Earth.* • *Where the currents are, if they're hot or cold depending on where they are over the world. Some move faster than others.* • *Trying to show you the temperature of water and direction of current flow.* • *Ocean currents and temperature of water around the globe. And its relationship to land masses it surrounds.* • *You see the continents again. And movement of water, temperature of water.*
Water temperature (n=22, 73.3%) • *Water flow and temperature change around the globe* • *Same thing. It helps to understand how water temperature is affected by movement of the earth. Water surface, elevation.* • *It's similar to the other one. It tells about currents and temperatures of ocean waters.* • *Once again, sea surface currents, and showing their movement and temperatures.*	Water temperature (n=21, 70%) • *Similar. Currents in the ocean, movement of currents in ocean with color-coded temperatures.* • *Sea surface temperatures and how they affect the whole world. It's amazing to see how they change.* • *The same thing. Sea surface temperature.* • *Ocean currents and temperature of water at the surface.*
Time frame (n=1, 3.3%) • *Surface temperatures. Compiled data from NASA. A lot of the same stuff as the table. See date range here, but not on table.*	Time frame (n=2, 6.7%) • *The same exact thing as the other one. The temperature of water and how currents move for one year.*

LEARNING

In addition to being tested on comprehension of the material, participants were asked whether they felt that they had learned anything new from the displays, and to explain what, if anything, they had learned (see Table 9). Most participants indicated that they had not learned anything new from the displays. While this is somewhat discouraging, participants' lack of perceived learning is likely due to the prior familiarity they had with oceans rather than an indication that the displays were ineffectual. Ocean currents and temperatures are not completely novel subjects for most people.

Table 9: Self-report of learning

	Y	N
First visualization – MP	14 (50%)	16 (50%)
First visualization – MT	14 (50%)	16 (50%)
Second visualization – MP	3 (21.4%)	**27 (58.7%)**
Second visualization – MT	**11 (78.6%)**	19 (41.3%)

Chi-square tests were conducted to determine whether learning varied by visualization format. After viewing the first visualization, there was no difference in reported learning by those who viewed the MP or MT ($p>.05$). However, reported learning after the second visualization did vary by format. Those who indicated learning something new after viewing the second visualization were more likely to have been MT users, while those who indicated not having learned something new were more likely to have been MP users, $\chi^2(1, N=60)=5.96$, $p<.05$. That is, viewing the MT after the MP was more likely to result in additional learning than viewing the devices in the opposite order. Why viewing the MT second was more likely to result in additional learning is unclear. It may be that viewing the entire global image on the MT second allowed participants to better understand the image that they previously viewed only one portion at a time on the MP. It may also have to do with the better image quality and ease of use/understandability that participants reported about the MT.

Those who did report learning something new from using the displays were asked to explain what they had learned (See Tables 10 and 11). Most of the answers provided after viewing the first visualization included mention of water temperature and sea current/movement. People overall reported less learning of new information after viewing the second visualization. This is unsurprising, given that they were being presented with the same information for the second time. However, those who did report learning something new from the second visualization that they did not learn from the first were asked to explain what they learned. Answers that mentioned sea current/movement were most popular.

Table 10: What users learned

	First Visualization		Second Visualization	
	MP (n=14)	MT (n=14)	MP (n=3)	MT (n=11)
Water temperature	**64.3%(n=9)**	**50%(n=7)**	0	45.5%(n=5)
Sea current/movement	**64.3%(n=9)**	**50%(n=7)**	**100%(n=3)**	**81.8%(n=9)**
One ocean/interconnectedness	7.1%(n=1)	21.4%(n=3)	---	---
Time scale	---	---	0	27.3%(n=3)

Table 11: Sample comments: What users learned

First Visualization: MP (n=14)	First Visualization: MT (n=14)
Water temperature (n=9, 64.3%) • *I was surprised how warm some of the currents were above Australia, near Indonesia. You can see the warm waters that come off of Africa and cause the hurricanes in the Caribbean and the Southern US.* • *I didn't realize that the water was that warm. I didn't realize the amount of warm water before, and where they are."* • *I guess the varying degrees. How much is warm, and the areas where it's cold, and where it changes to warm.*	Water temperature (n=7, 50%) • *How it's warmer along the equator. The temperature increase, the temperature of the water.* • *The sea temperatures. I didn't really know how they could change across the globe/map.* • *I didn't realize the water was that warm.*
Sea current/movement (n=9, 64.3%) • *I didn't know how the current went, and how they move, tides.* • *I didn't know there were so many different currents. I probably didn't know anything about currents after all. I thought they went all in the same direction around Earth.* • *I had no idea that the currents went in so many different directions.*	Sea current/movement (n=7, 50%) • *I didn't know how these currents swirl around Earth. I thought it was linear.* • *Because I don't know anything about this. I didn't realize that's what currents were like and what they did. I didn't know anything about currents.* • *How the ocean currents were faster in some places. Where they're not.*
One ocean/interconnectedness (n=1, 7.1%) • *I thought it was more of an ocean to ocean thing. I didn't realize it was one ocean. And greater temperature differences than I thought in a short distance.*	One ocean/interconnectedness (n=3, 21.4%) • *I didn't know that it was actually just one giant sea.*

Second Visualization:MP (n=3)	Second Visualization: MT (n=11)
Water temperature (n=0)	Water temperature (n=5, 45.5%) • *Based on the changing of the year time, the water temperature changes.*
Sea current/movement (n=3, 100%) • *I saw a different angle of the currents. I'm also seeing the tilt of the earth's axis.*	Sea current/movement (n=9, 81.8%) • *I have a better picture in my head. I can see patterns to the currents that I didn't see before.* • *The horizontal movement of the ocean. Temperature at poles.*

	• *It's easier to see the flow from the poles. How they interact/intermix North-South/South-North.*
Time scale (n=0)	Time scale (n=3, 27.3%) • *I wasn't aware of time frame in the other one.*

CLARITY OF VISUALIZATIONS

In addition to comprehension and learning assessments, participants were asked to indicate whether they had trouble understanding the displays. After viewing only the first visualization, participants were asked if there was anything not clear about it (see Table 12). The most common answer provided by those who viewed the MP first concerned being unclear about where on Earth they were looking. The most common answer provided by those who viewed the MT first was that nothing was unclear; however, the most common confusion again stemmed from not being clear about where on Earth they were looking. This confusion was common among participants in large part because some people had trouble orienting themselves to the gray land and colored water of the data presentation.

Table 12: Anything not clear*

	MP (n=30)	MT (n=30)
Where on the Earth we are looking	**33.3% (n=10)**	26.7% (n=8)
What was being measured	20% (n=6)	10% (n=3)
The units of measurement	6.7% (n=2)	10% (n=3)
What the time scale was	3.3% (n=1)	10% (n=3)
What the colors represent	0	3.3% (n=1)
What to do/how to use	20% (n=6)	13.3% (n=4)
Nothing was unclear	30% (n=9)	**46.7% (n=14)**

*Multiple responses were possible (excluding the Nothing category)

TO WHAT EXTENT DOES THE DISPLAY FORMAT OF THE DATA VISUALIZATION CHANGE USER ATTENTION TO SPECIFIC COMPONENTS?

DISPLAY USAGE

Participants were asked to use the MT and MP displays for as little or as much time as they wanted, and to let the experimenter know when they were done. When considering only order, participants spent slightly longer time at the first device, which is not surprising since the second device presented the same information and was accompanied by the same text panel. When considering only format, participants spent slightly longer time with the MP (see Table 13). It is unclear whether this is an indication that participants found the device more interesting, or whether it was due to the novelty of the device and/or its controls being more complex.

Table 13: Time

	Min (mm:ss)	Max (mm:ss)	Median (mm:ss)
First device (n=60)	0:33	6:24	**1:42**
Second device (n=59)	0:19	7:50	1:28
MP (n=59)	0:33	7:50	**2:00**
MT (n=60)	0:19	3:56	1:21

Items to Notice about the Visualizations

Participants were asked what they thought the most important thing to notice was about the visualizations (See Tables 14 and 15). Most of the answers contained mention of water temperature and sea current/movement.

Table 14: Items to notice about the visualizations

	MP (n=60)	MT (n=60)
Water temperature	**60%(n=36)**	**50%(n=30)**
Sea current/movement	35%(n=21)	**50%(n=30)**
Interconnectedness/one ocean	6.7%(n=4)	11.7%(n=7)
Abundance of water	6.7%(n=4)	5%(n=3)
Time scale	0	3.3%(n=2)
Map/display	18.3%(n=11)	3.3%(n=2)
Other	10%(n=6)	13.3%(n=8)

Table 15: Sample comments: Items to notice about the visualizations

MP (n=60)	MT (n=60)
Water temperature (n=36, 60%) • *The colors. They indicate temperature. I think that's the whole purpose of this.* • *The warmer water is at the equator, which makes sense. It would be important to notice that there are some warmer areas near N America. Wide variety of water temperatures around the globe.* • *The distinction between warm and cold areas. Currents move faster in warmer water.* • *The currents going in different directions. That water temperatures change. That's important because it kills fish. Water shouldn't be that warm. It's not good for animal/plant life.* • *The temperatures. I would like to know*	Water temperature (n=30, 50%) • *The shift in temperature. How the water in one place changes temperature.* • *I think the temperature disparity is what struck me, initially.* • *Same thing. The color scale and how it indicates temperature.* • *The amount of hot current that we have that is spreading away from the equator, where you expect the water to be warmer.* • *The water temperatures in relation to where they are on Earth.* • *Different temperatures of water. It's colder along the bottom. Warmer in the middle.*

more about temperatures and why they're so different. And how it relates to the temperature, how the movement of moon is associated with temperature. • *I guess that currents have different temperatures and are affected by them. Re-affirms that warmer current is closer to the equator, and colder close to the poles.*	
Sea current/movement (n=21, 35%) • *The patterns. The shifting of the water current.* • *The patterns of the water (movement and temperature), and how does it affect the fish.* • *Probably that all the bodies of water are moving. Everything is moving. The water moves faster in warmer areas.* • *The currents are always moving, I guess.* • *I think I notice that many things (water patterns) stay the same, and many things change. Water patterns near continents are more intresting to watch than in the oceans.*	Sea current/movement (n=30, 50%) • *The currents and the way they're flowing. They seem to do different things in different places. There must be a reason for it.* • *What it's about, sea surface currents.* • *Really, all the activity around the equator. There's more activity there.* • *The movement of the water, the ocean currents. Circular in some cases.* • *The constant motion, constant mixing of the oceans.* • *All the different directions the currents are going in different areas.*
Interconnectedness/one ocean (n=4, 6.7%) • *Maybe that there are just no borders to the ocean. So everyone is affected by what goes into it. Land is more defined.* • *How much of a difference there is between hot and cold. And it shows the movement and interactions of how all oceans connect.*	Interconnectedness/one ocean (n=7, 11.7%) • *It helps to understand that when something is going on in Albuquerque, it's not because we're in a bad state. But it's something global. It all works together. It's not just one part of earth.* • *That it's all connected, the oceans are all connected to each other.* • *That the surface sea currents, it's a continuous entity. What happens in one part of the world affects another.*
Abundance of water (n=4, 6.7%) • *How much water there is. Water is so dominant.* • *I think the most striking thing is the amount of water there is. The Earth is made up of a lot of water.*	Abundance of water (n=3, 5%) • *The temperature changes. That there's different temperatures across. How water encompasses everything.*
Time scale (n=0)	Time scale (n=2, 3.3%) • *Probably the dates and temperature. It's*

	time lapse.
Map/display (n=11, 18.3%) • *That the earth is round. The parts on the Northern ends are not as big as they seem on a flat presentation. Most of the globe is water.* • *This one shows earth's rotation as well as currents. So it magnifies the amount of change that's going on, the movement.* • *The earth's rotation, and the direction of the currents while it's rotating.*	Map/display (n=2, 3.3%) • *Just realizing the land forms are gray, so you can really appreciate what's going on.*
Other (n=6, 10%) • *Not sure. It's very fluid, dynamic.* • *That you'll never convince me of a Big Bang because it's all too perfect.*	Other (n=8, 13.3%) • *It's just pretty to look at.* • *It's just a vast area shown.*

CONCLUSIONS

- Both the MP and MT displays were able to convey the intended information to library patrons. Therefore, both types of displays could potentially be successful if used in museum/library exhibitions.
- There is some indication that the MT device might be a better learning tool, but additional research is needed to better understand why viewing the MT after the MP resulted in additional learning.
- Both devices convey a sense of complex Earth systems sciences to the users.
- The MP may be slightly more difficult for individuals to use, resulting in a somewhat longer stay time.
- The choice of format used in future exhibitions might depend on whether being able to compare various parts of the Earth is important. The MP format allows for users to focus on one part of the Earth at a time, whereas the MT allows a user to see the entire global image at once.

RECOMMENDATIONS FOR FUTURE RESEARCH

- Comparison of MT and MP displays that contain the same number of controls to investigate whether users would still find the MT easier to understand/use under these conditions.
- Comparison of MT and MP devices without text panels to better understand the role of the text panels in comprehension and learning in these data visualization displays.
- In order to better understand the potential learning that could result from using these devices, data visualization topics used in future research should be less familiar to people, and participants' previous knowledge about the topics should be measured.

APPENDIX

COMPARISON STUDY: MAGIC PLANET VS. MT TABLE

Date (dd/mm/yy)	
Observer Initials	
Sex	
Visitor Unique ID	

First visualization (circle one): Magic Planet MT Table

Start time (mm:ss) ____:____ Stop time (mm:ss) ____:____

After the first visualization interview

1. Can you tell me what this visualization was about?

2. Based on what you know about this topic or topics from before you saw this presentation, did you learn anything new? ❑ Yes ❑ No

3. Can you tell me what you learned?

4. Mark the one statement that reflects most closely your thoughts when viewing the visualization:

❑	I appreciated how realistic the information appeared.
❑	It helped me visualize specific events.
❑	It helped me to visualize certain concepts of time and scale.
❑	I learned or was reminded that the Earth is always changing and evolving.
❑	It made me think about the complex interrelations in Earth Systems.
❑	I was amazed at the beauty of what was shown.
❑	It helped me understand global processes.
❑	I felt a sense of the vastness of Earth.
❑	I felt a need to take better care of Earth.
❑	It helped me better understand geography of Earth.
❑	None of these options accurately reflect my thoughts.

5. Was there anything not clear about this visualization?
   - ❑ What was being measured
   - ❑ The units of measurement
   - ❑ What the colors represent
   - ❑ What the time scale was

- ❑ Where on the Earth we are looking
- ❑ Other: _____

6. What do you think is the most important thing to notice in this visualization?

Second visualization (circle one): Magic Planet MT Table

Start time (mm:ss) ____:____ Stop time (mm:ss) ____:____

After the second visualization interview

7. Can you tell me what this visualization was about?

8. Did you learn anything from the second visualization that you did not in the first one?
   ❑ Yes ❑ No

9. Can you tell me what you learned?

10. Mark the one statement that reflects most closely your thoughts when viewing the visualization:

❑	I was amazed at the beauty of what was shown.
❑	It helped me better understand geography of Earth.
❑	I felt a need to take better care of Earth.
❑	I appreciated how realistic the information appeared.
❑	It made me think about the complex interrelations in Earth Systems.
❑	I learned or was reminded that the Earth is always changing and evolving.
❑	It helped me understand global processes.
❑	It helped me visualize specific events.
❑	I felt a sense of the vastness of Earth.
❑	It helped me to visualize certain concepts of time and scale.
❑	None of these options accurately reflect my thoughts.

11. What do you think is the most important thing to notice in this visualization?

12. Now that you've seen the visualizations in both formats, what was different about the two?

13. Were there aspects of this way of seeing the visualization (choose last site seen: on the surface, on the sphere) that were better for you?

14. Were there aspects of that way of seeing the visualization (choose first site seen: on the surface, on the sphere) that were better for you?

15. Is this the first time you've seen a visualization presented on a sphere?
    ❑ Yes ❑ No ❑ Not sure

16. What race/ethnicity do you consider yourself?
    ❑ African American/Black
    ❑ American Indian/Native Alaskan
    ❑ Asian / Asian American
    ❑ Latino(a) or Hispanic
    ❑ Native Hawaiian/Pacific Islander
    ❑ White
    ❑ Prefer not to answer

17. What is the highest level of education that you have completed? (mark one)
    ❑ High school or less
    ❑ 1-2 years of college or no degree
    ❑ Associate's degree
    ❑ Bachelor's degree
    ❑ Graduate/professional degree
    ❑ Prefer not to answer

18. What year were you born? _____

Earth's One Ocean

Ocean currents are the movement of both surface and deep water throughout Earth's oceans. Much like the circulatory system in the human body, Earth's currents transport nutrients and heat to all corners of the planet. This is possible because all of Earth's oceans are actually one giant sea, connected by global currents.

Ocean currents are caused by many different factors, such as breaking waves, wind, air temperature, and the tides caused by our Moon. These currents influence weather and climate across the planet.

Credit: NOAA

This image shows a simplified view of Earth's current systems. The visualization on the touch table will help you better understand how these large current systems change over time.

What's on the table?

The visualization on the touch table shows global sea surface current flows. The colors represent the surface temperature, blue being the coldest, and red the warmest (see key below). This NASA/NOAA visualization is a combination of physical data and computer models.

Credit: U.S. Navy

Sailors assemble a drifting buoy used to measure ocean currents before deploying it from the fantail of the Nimitz Class aircraft carrier.