Science On a Sphere®:

Cross-Site Summative Evaluation

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About the Institute for Learning Innovation:

Established in 1986 as an independent non-governmental not-for-profit learning research and development organization, the Institute for Learning Innovation is dedicated to changing the world of education and learning by understanding, facilitating, advocating and communicating about free-choice learning across the life span. The Institute provides leadership in this area by collaborating with a variety of free-choice learning institutions such as museums, other cultural institutions, public television stations, libraries, community-based organizations such as scouts and the YWCA, scientific societies and humanities councils, as well as schools and universities. These collaborations strive to advance understanding, facilitate and improve the learning potential of these organizations by incorporating free-choice learning principles in their work.

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Executive Summary

Since 2008, The Institute for Learning Innovation (ILI) has been working with the NOAA Science On a Sphere® (SOS) program staff to investigate the nature and range of the impact that the sphere has on audiences who interact with it. The Sphere is an innovative way to visualize data, early evaluation has seen users react in very different ways, from curiosity about how the data in the visualizations is gathered to a sense of wonder about the vastness and the complexity of Earth. This summative evaluation was designed to set a baseline for outcomes, testing which potential outcomes are most likely for Sphere users to determine which outcomes and questions bear further investigation.

The results of this evaluation are framed around five questions:

1. What does the literature say about the learning potential of visualization experiences like the sphere?
2. What evidence exists for the sphere's learning potential in previous evaluation studies conducted to date?
3. To what degree and in what ways do visitors perceive that they learn something new from their sphere experience? How do factors such as Sphere site, presentation mode, and content influence visitors' perceptions?
4. Which learning outcomes do visitors feel best describe their experience with the sphere? How do factors such as sphere site, presentation mode, and content influence visitors' selection of learning outcomes?
5. In what ways do visitors perceive that the Sphere's 3-D presentation of information influences their learning?

There were many useful findings and directions for further research, these are presented with detailed analysis and extensive contextualization within in the body of this report.
Key overall findings about the sphere were:

- Visitors felt they learned new information.
- The sphere supports understanding complex processes and phenomena.
- Visitors feel seeing information on the sphere is more realistic and provides more perspective.
- Facilitation correlates with learning.

The final sample includes 691 data points from 16 sphere sites, primarily gathered by staff at each site. All of those interviewed for this study were adults and the interviews consisted of a nearly equal split between men and women. Eighty percent of those sampled were seeing the sphere for the first time.

Visitors felt they learned new information.
When asked if they had learned something new, 71% of interviewees responded they had and were able to provide specific examples of what they had learned, ranging from the amount of earthquake activity in the Caribbean to how Forest fires change air quality worldwide. Further

questions point to the nature of the sphere itself. Sphere viewers repeatedly used the terms *3D*, *Real*, *Perspective* and *Visual,* when describing the elements of their Sphere experience.

The sphere supports understanding complex processes and phenomena.
Visitors were asked to rate a series of statements to choose the top three that best reflected their Sphere experience. What emerged most often was statements that reflect the realism of the Sphere, how it emphasizes complexity and change in Earth (or other planetary) Systems. When combining all the results, over a third of the visitors stated that it was the realism of the data on the Sphere that stayed with them, and nearly a third commented that the Sphere helped them visualize specific events. Visitors also commented that the Sphere helped them with aspects of time and scale. As one visitor commented "*I can see the time lapse, how things change over time*." While not discounting the reaction of the beauty of the sphere (nearly a quarter of the visitors mentioned this aspect), the main set of statement are about the visualization and synthesis of events and systems. Least common were the more affective statements about the Earth or content, such as attachment to the Earth as home, or a religious or spiritual connection with the planet.

Visitors feel seeing information on the sphere is more realistic and provides more perspective.
When visitors were asked whether the information on the sphere changed how they understood the information, 82% said yes, seeing it displayed on a sphere changed their understanding of the information. As one visitor said: "*Anytime you can see 3D, it's easier to grasp concepts of currents, airflow and systems. It helps kids especially to understand the concepts*." Other visitors commented that a "*A flat map doesn't give the real scope of how sea level affects the world."* and *"It brings it to life."*

Facilitation correlates with learning.
While visitors who saw facilitated and unfacilitated presentations both report learning new information, facilitation correlates strongly with visitors' perception of learning. Those visitors who saw a facilitated presentation were substantially more likely to state they had learned something new. Facilitation also correlates with specific outcomes, including: increased understanding of time and scale, increased understanding of constant change of the Earth and increased perception of the sacredness of the Earth and need to take care of it. In the future, NOAA may wish to consider expanding facilitated programming in conjunction with the sphere.

The study conducted here was a vast exploratory study, designed to document perceived learning, create and test an initial set of outcomes and to generate correlations worth researching in the future. Now that a baseline set of outcomes across many sphere sites has been established, we would recommend future studies attempt to limit or control for the number of potentially confounding variables. These studies would likely be based at a much smaller number of sites, even a single site, under carefully controlled circumstances. We would recommend further exploring the following issues:

1. The Impact of Facilitation,

2. Two-Dimensional versus Three-Dimensional Presentation Systems,
3. Controlled Studies on Content, and
4. Perceived versus Actual Learning.

Introduction

Science On a Sphere® (SOS) is a spherical projection system invented by the National Oceanic and Atmospheric Administration (NOAA) that shows high resolution video and geographic data sets via four projectors set at ninety degrees onto a 68 inch diameter spherical screen. Invented in 1995 by Dr. Sandy MacDonald at NOAA, SOS was patented in 2005. It is considered innovative because of its ability to see global data visualizations without distortion and because its large network of institutions using SOS, allows significant collaboration among scientists, visualization experts and educators. As of this writing, SOS is installed in a total of 49 museum locations, including both domestic and international locations.

The NOAA Office of Education has sponsored a series of funding opportunities for museums and other educational institutions to support installation of a sphere and associated costs in maintaining the sphere. Through these funding opportunities, the Office has also supported the creation of a number of movies and short presentations. Other institutions and agencies, most notably NASA, have also contributed datasets and movies for the larger sphere network to use. All movies and datasets developed with NOAA funds are available free of charge for each of the Sphere sites to use. Datasets, including near real-time datasets such as volcanic ash distribution or hurricane pathways, are stored in an online library maintained by NOAA Earth System Research Laboratory (ESRL). There are over 250 datasets currently available to the network. The NOAA Office of Education convenes regular meetings of SOS institutions (The SOS User Network) in order for the SOS sites to share projects and findings, and collaborate on projects.

Background on the Evaluation

Since 2005, NOAA has made a significant investment in spherical data visualization systems, both SOS and other systems, to support science learning. This investment stems from NOAA's overall education goals. Those goals, as defined in the 2009 Education plan are:

Goal 1: Environmental Literacy: An environmentally literate public supported by a continuum of lifelong formal and informal education and outreach opportunities in ocean, coastal, Great Lakes, weather and climate sciences.

Goal 2: Workforce Development: A future workforce, reflecting the diversity of the Nation, skilled in science, technology, engineering, mathematics, and other disciplines critical to NOAA's Mission.[1]

While NOAA has not yet defined specific learning goals for SOS, the anticipated goal is that interaction with the 3D, large-scale spherical format of the Sphere will have a beneficial learning impact on SOS users. The sphere is a relatively new way to visualize data: early

[1] http://www.education.noaa.gov/plan/09_NOAA_Educ_Strategic_Plan_Color.pdf

evaluation has seen users react in very different ways, from curiosity about how the data in the visualizations is gathered to a sense of wonder about the vastness and the complexity of Earth. (Apley, 2004) Despite strong encouragement and evaluation funding from the NOAA Office of Education, to date, the majority of the SOS sites have focused on formative evaluation of the sphere within their particular setting, rather than investigating the overall impact of the sphere on visitors. In response, NOAA funded a grant opportunity for a summative evaluation of the sphere to provide deeper understanding of its user impact. To that end, the Institute for Learning Innovation was awarded the grant (NA 08SEC-4690057) and began working with NOAA SOS program staff in 2008. The overall focus of the evaluation is to investigate the nature and range of the impact that the sphere has on audiences who interact with it.

The results of this evaluation are framed around five questions:

1. What does the literature say about the learning potential of visualization experiences like the sphere?
2. What evidence exists for the sphere's learning potential in previous evaluation studies conducted to date?
3. To what degree and in what ways do visitors perceive that they learn something new from their sphere experience? How do factors such as sphere site, presentation mode, and content influence visitors' perceptions?
4. Which learning outcomes do visitors feel best describe their experience with the sphere? How do factors such as sphere site, presentation mode, and content influence visitors' selection of learning outcomes?
5. In what ways do visitors perceive that the sphere's 3-D presentation of information influences their learning?

Methodology

ILI employed a combination of methods to execute this summative evaluation study: 1) a literature review of empirical studies related to data visualization; 2) a review of previous evaluation studies conducted with the sphere; and 3) semi-structured interviews with visitors who interacted with the sphere at one of 16 sites across the United States. Each of these methods is described in more detail below.

Literature Review

At multiple points during the course of this study, ILI conducted literature searches and reviews on subjects related to Science On a Sphere® in order to review what was known about data visualization, identify the key issues within the data visualization field, contextualize the findings of this study, and to help guide future research studies. Searches were performed in academic databases such as Springerlink, ScienceDirect, ACM, and JSTOR, as well as within specific academic journals and Google scholar. The literature in this field remains quite limited, so we used an extensive set of search terms in order to find literature from related fields that may be useful. Examples of the search terms used include the following:

- Data visualization
- Spherical visualization
- Geographical visualization
- Learning
- Education
- Spherical projection
- Display systems
- Projection systems
- Large scale immersive displays

Review of Previous Evaluations

ILI conducted a review of all of the previous known evaluations of the sphere in order to inform this work. In reviewing the previous evaluations, researchers were looking to better understand the nature of learning with the sphere, what previous studies had accomplished, ascertain any factors that may influence learning with the sphere and ultimately to determine previously defined outcomes that may be relevant to this study.

All SOS sites funded by NOAA were required to complete some form of evaluation, and NOAA requested that copies of the evaluations be posted on the NOAA Science On a Sphere® site, http://www.oesd.noaa.gov/network/SOS_evals/index.html. NOAA has regularly requested sites to report on evaluations. If the information sheets revealed an evaluation that we did not previously have, ILI researchers contacted the site and requested the evaluation. There were 20 evaluations available either through the NOAA website or upon direct request of the site; of those, two were front-end, one was summative, and the remainder were formative or remedial. Identifying information on those evaluations can be found in Table 1.

Table 1: Prior Evaluations Reviewed

Site	Author	Date	Title	Evaluation Focus
Bishop Museum	Pacific Resources for Education and Learning	October, 2007	Evaluation of Bishop Museum's Science on a Sphere	Remedial
Fiske Planetarium and Science Center of Colorado University	Susan Lynds Cooperative Institute for Research in Environmental Sciences (CIRES) University of Colorado	May, 2008	Science on a Sphere Assessment Data Astronomy Day, April 12, 2008	Formative
Maryland Science Center	Alice Apley, RMC Research Corp.	August 1, 2004	Science on a Sphere Front-End Evaluation	Front-end
Maryland Science Center	People, Places & Design Research	June, 2007	Supplemental Interpretive	Formative

			Components	
McWane Science Center	Unknown	Unknown	Assessment Summary I	Summative
McWane Science Center	Unknown	Unknown	Science on a Sphere Assessment Data	Summative
Nauticus The National Maritime Center	Randi Korn & Assoc.	Summer 2006	Results of the Survey	Summative
Science Museum of Minnesota	Amy Grack Nelson & Kirsten Ellenbogen	May 25, 2006	Science On a Sphere Front-End Evaluation Report	Front-end
Science Museum of Minnesota	Amy Grack Nelson & Dave Ordos	November, 2006	College of St. Catherine STEM Course Science-on-a-Sphere Post-Visit Survey Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Murphy Pizza	December, 2006	Augsburg Oceanography Course Science on a Sphere Post-Visit Survey Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Dave Ordos	December, 2006	College of St. Catherine STEM Course Science-on-a-Sphere Post-Visit Survey Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Dave Ordos	January, 2007	University of St. Thomas Science of Natural Hazards Course Science on a Sphere Post-Visit Survey Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Dave Ordos	January, 2007	St. Olaf College Introduction to Environmental Studies Course Science on a Sphere Post-Visit Survey Report	Formative
Science Museum of Minnesota	Dave Ordos & Amy Grack Nelson	December, 2007	College Class SOS Visit: College of St. Catherine POST-VISIT SURVEY REPORT	Formative
Science Museum of Minnesota	Amy Grack Nelson	January 15, 2007	Footprints: Tracking Report	Formative
Science Museum of Minnesota	Amy Grack Nelson	January 17, 2007	Footprints: Exit Interview Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Beth Janetski	March 2, 2007	Science On a Sphere Lobby Interview Report	Formative

Science Museum of Minnesota	Amy Grack Nelson & Levi Weinhagen	March 29, 2007	Science on a Sphere Interpretive Features: Prototyping Report	Formative
Science Museum of Minnesota	Amy Grack Nelson & Murphy Pizza	March, 2008	Oceanography Course Visit to Science on a Sphere Post-Visit Survey Report	Formative
The Tech Museum of Innovation	Randi Korn & Assoc.	July 1, 2007	View from Space Remedial Evaluation	Remedial

Sampling Frame

Under careful consideration, we excluded certain facilities from the study based on their unique properties. At the time the grant award for this evaluation was made, the SOS network was comprised of 22 Museums and Science Centers, 1 university and 3 other facilities. Our intent with this grant was to investigate outcomes in a broad sense, across the spectrum of sphere installations and experiences. However, some sites did not fit well into the core study. For example, James Madison University uses their SOS as a tool for training pre-service teachers. The nature of their engagement and the length of their exposure to the sphere is fundamentally different than that of a visitor to most of the other sphere sites; therefore, we did not include JMU within the evaluation. Some visitor center-base spheres, such as the NOAA Earth System Research Lab, the NASA Goddard Space Flight Center, Visitors Center, and NOAA's National Severe Storms Laboratory declined to provide data on the grounds that there sites were too dissimilar to the other SOS sites. Some sites were excluded from the sample based on their very recent installations of the sphere, as they were still fine-tuning the format and display options, such as the Oregon Museum of Science and Industry and the Alaska State Museum. Still other sites were requested to submit data, such as the Fiske Planetarium and Nauticus, but did not do so. Finally, Ocean Exploratorium did submit data, but that data was not included in this review as it was collected in a way inconsistent with the protocol.

This list represents the 16 study sites included in the review:

1. Bishop Museum
2. Boonshoft Museum of Discovery
3. Clark Planetarium
4. Hatfield Marine Science Center
5. `Imiloa Astronomy Center of Hawai`i
6. Lawrence Hall of Science
7. McWane Science Center
8. Maryland Science Center
9. Museum of Science and Industry, Chicago
10. North Carolina Aquarium
11. National Museum of Natural History
12. National Renewable Energy Laboratory
13. National Zoological Park

14. Science Museum of Minnesota
15. The Tech Museum
16. The Whitaker Center of Science and the Arts

The final list of sample SOS sites represents a variety of geographic locations, a range of audience populations and numbers, and a variety of sphere presentations types. All but one of the sites were informal science learning sites. Where bias in sampling may exist is the fact that only one visitor center site, the National Renewable Energy Laboratory, participated. One zoo, one aquarium, and one planetarium participated in the study. Many institutions were primarily science focused, but others such as the Whitaker and the ‘Imiloa Astronomy Center also had strong arts and culture components.

Overall, there is significant variety in where the spheres are placed within each site. Some of the spheres are situated within a theater; some spheres are in a lobby setting. Some spheres are integrated within a specific exhibit, and the exhibit and SOS content are designed in an integrated fashion. Each of these contexts was represented within this sample.

In addition to the differences of location and context of the sphere placement, there are differences in the presentation of the sphere from site to site. At some sites, a facilitator or docent presents the datasets on the sphere at set times, talking the audience through what they are seeing on the sphere and at times answering questions about the information presented. For some sites, such as the Whitaker Center and the Museum of Science and Industry, this facilitated presentation is similar to a theatrical show, with trained performers as the facilitators. Not all sites provide facilitated content, however, some sites, such as the National Museum of Natural History, do not provide any facilitation, but run an automated set of data visualizations that play in a loop on the sphere. Some sites offer facilitated presentations at times, and auto-run visualizations at others. Finally, there are a few sites that run data visualizations or other content on the sphere through visitor-initiated actions, such as through a kiosk.

Another site difference is the inclusion of the globe at Hatfield Marine Science Center (HMSC). HMSC does not have SOS, but has a different commercial spherical visualization system called Magic Planet. Magic Planet is available commercially, and comes in a range of sizes and with customizable features, such as options for visitor interaction. The Magic Planet at HMSC is one of the larger versions, approximately 4 feet in diameter, though is not as large as SOS. Due to small sample size, this study did not investigate the potential differences in outcomes between use of the Magic Planet and use of the sphere.

Table 2: Background Information on Sites

Site	Annual Overall Visitorship	State	General Sphere Setting
Bishop Museum	300,000	HI	Separate room next to exhibition
Boonshoft Museum of Discovery	225,000	OH	Separate Room
Clark Planetarium	350,000	UT	Lobby
Hatfield Marine Science Center	150,000	OR	Within Exhibition
`Imiloa Astronomy Center of Hawai`i	58,000	HI	Separate room
Lawrence Hall of Science	200,000	CA	Separate Room
Maryland Science Center	500,000	MD	Standalone
McWane Science Center	300,000	TX	Lobby
Museum of Science and Industry, Chicago	1,500,000	IL	Theater
National Museum of Natural History	7,000,000	DC	Separate room within Exhibition
National Renewable Energy Laboratory	N/A	CO	Theater
National Zoological Park	3,000,000	DC	Within Exhibition
North Carolina Aquarium	300,000	NC	Separate Room
Science Museum of Minnesota	800,000	MN	Separate Room
The Tech Museum	600,000	CA	Separate Room within Exhibition
The Whitaker Center of Science and the Arts – Harsco Science Center	110,000	PA	Within Exhibition

Each site composes its own "playlist", a set of data visualizations to be shown on the sphere. A typical playlist might include anywhere from 12-20 data visualizations over 1-3 content categories. Currently there are over 250 data visualizations within the main SOS network library, which fall roughly into 4 larger content categories. Those content categories are: Ocean, Astronomy, Atmosphere, and Land. For instance, there may be multiple visualizations on change in ocean temperature, direction of the ocean currents, location and change in size of the Great Pacific Garbage Patch. Although these are all separate data visualizations, there are categorized within the same content category, Ocean. In addition, there have been several films developed for the sphere by NASA and others, including *Frozen*, *Earth Our Only Home*, *Energy Planet*, *Footprints*, *Blue Planet* and *Coral Reef*. Due to the slightly different experience of watching a film rather than a series of data visualizations, these films were noted and coded separately from the content categories.

Visitor Interviews

To assess visitors' perceptions of learning from their sphere experience, semi-structured interviews were conducted with visitors in 16 sites across the country. At each site, interviews were conducted by site staff. As the collection of evaluation data was a required part of the NOAA Office of Education grants, each site was asked to contribute 40-60 interviews as part of their fulfillment of their grant requirements. As most of the participating sites lacked trained evaluation data collectors, ILI, with the help of a professional video company, created a set of evaluation training modules for staff and volunteers who would be participating in the data collection. These modules were designed as a series of short videos, so that individuals could gain training on specific issues. There were 7 modules in total:

1. Project Overview
2. Evaluation Background
3. Preparing for Data Collection
4. Space Orientation
5. Approaching Visitors
6. Interview Techniques
7. Recording and Managing Data

The modules were posted on the NOAA Science on the sphere website (http://sos.noaa.gov/support/flash/ili/) and made available to the sites on DVD.

Site staff collected data from October 1, 2009 to February 23, 2010. Sites were asked to collect 40-60 randomly sampled visitor interviews of visitors leaving the sphere area. In addition, ILI sent data collectors to the following sites due to staff capacity issues at those sites: Boonshoft Museum of Discovery, The Whitaker Center of Science and the Arts, North Carolina Aquarium, Lawrence Hall of Science and the Museum of Science and Industry (Chicago).

For each interview, data collectors observed and noted what types of content were being shown on the sphere prior to the visitor leaving.   Due to the amount of data to be collected and the variation between sites, no tracking or duration data was collected. Data collectors were instructed to interview visitors would had been watching the content a minimum of one minute, in keeping with the timing set during the Science Museum of Minnesota evaluations. Visitors were recruited after they had interacted with the sphere and were leaving the immediate sphere area. Visitors' perceptions of learning were assessed in two ways: first through a series of open-ended questions and then in an exercise where visitors ranked a series of outcome-based statements about ways they may have benefited from their sphere experience.

The development of the rank-based outcomes stems from the initial review of prior evaluations of the sphere. During the review, all potential outcomes mentioned within the evaluations were gathered. ILI then went through a process of examining each outcome and clarifying it. For example, experiencing a sense of awe at seeing the sphere could be interpreted as feeling a sense of wonder at the beauty of the sphere, or it could mean appreciating the complexity of a particular data visualization. Once ILI had expanded this outcome set from the original set of evaluations, researchers sought feedback on the new set of outcomes from the NOAA Education Office team members and to the SOS network at large. The final set of 14 outcomes for testing was then reviewed by the NOAA Education Office staff.

Assessing outcomes in both an open-ended and closed-ended fashion was critical in this particular study, as one of the main goals of the study was to determine the type of outcomes that occur when viewing the sphere. While the team needed to provide a closed-ended set to assess frequency, it was also necessary to include open-ended questions to allow unanticipated outcomes to emerge.

Demographic and psychographic information was also gathered including race/ethnicity, gender, age, group size and ages of group members, and prior visitation to that location and to other museums. See Appendix B for the exit interview instrument.

Sampling

A total of 691 visitors were interviewed across the 16 sphere sites. Table 3 describes how many visitor interviews were conducted at each site.

Table 3: Sites and Number of Visitor Interviews Conducted

Site	Percent of Total Sample	Sample Size
Bishop Museum	6.5%	45
Boonshoft Museum of Discovery	10.1%	70
Clark Planetarium	5.2%	36
Hatfield Marine Science Center	5.8%	40
`Imiloa Astronomy Center of Hawai`i	6.8%	47
Lawrence Hall of Science	6.8%	47
McWane Science Center	3.6%	25
Maryland Science Center	5.4%	37
Museum of Science and Industry, Chicago	6.8%	47
North Carolina Aquarium	6.9%	48
National Museum of Natural History	6.4%	44
National Renewable Energy Laboratory	4.2%	29
National Zoological Park	6.8%	47
Science Museum of Minnesota	8.7%	60
The Tech Museum	7.4%	51
The Whitaker Center of Science and the Arts	2.6%	18
Total	100.0%	691

Interviews were conducted with almost equal numbers of men and women (See Table 4.)

When asked if they were seeing the sphere for the first time, eighty percent of those interviewed said yes. Another 20% had seen the sphere one or more times, including for some individuals at multiple SOS sites.

While this study was designed to be implemented with adults over age 18, occasionally when in-the field data collectors were interviewing a family group, the adults deferred their answers to an individual under 18 within their group. The largest number of the adults (44%) were between ages 30-49 (See Table 5.)

Table 4: Gender of Visitors Interviewed

Sex	Percent	Frequency
Male	50.7%	345
Female	46.9%	323
Missing data	2.5%	17
Total	100%	668

Table 5: Age of Visitors Interviewed

Age	Percent	Frequency
Under 18	2.5%	17
Age 18 - 29	15.5%	107
Age 30 - 39	21.9%	151
Age 40 - 49	22.1%	153
Age 50 - 59	15.2%	105
Age 60 - 69	10.7%	74
Age 70 and up	2.7%	19
Missing data	9.4%	65
Total	100.0%	691

We asked visitors to self-identify their race/ethnicity, based on modified U.S. Census race/ethnicity categories. Nearly three-quarters of the interviewees were white, with the next most common ethnicity being Asian or Pacific Islander (Table 6). Hispanic and Latino visitors made up almost 4% of the sample, and African Americans another 2.5%. Just over 4% declined to answer, and 2.5% stated they were a race/ethnicity other than those noted.

Table 6: Ethnicity of Visitors Interviewed

	Percent	Frequency
White	74.4%	514
Asian / Pacific Islander	11.0%	76
Hispanic/Latino	3.9%	27
Black or African American	2.5%	17
American Indian/Alaskan Native	1.4%	10
Other	2.5%	17
Missing data	4.3%	30
Total	100.0%	691

Most interviewees viewed SOS in social groups, with 78% in a group of friends or family members, and another 10% viewed is as part of an organized group, such as a tour group. Over 8% of the interviewees viewed the sphere alone (Table 7).

Table 7: Social Group Composition of Visitors Interviewed

Social Group	Percent	Frequency
With friends or family	78.1%	540
Organized group	9.8%	68
Alone	8.7%	60
Missing Data	3.3%	23
Total	100.0%	691

Just under half the data was gathered on weekends. This was by design, as the visitation to most sphere locations is stronger on weekends (Table 8).

Table 8: Weekday/Weekend Distribution of Data Collection

	Percent	Frequency
Weekday Visitors	56.3%	385
Weekend Visitors	43.7%	299
Missing Data	--	--
Total	100%	684

The sphere's presentation mode varied within each site, as did the resulting content presented. At some sites the presentation was facilitated and at others the sphere ran on auto-programming. In both the facilitated and the auto-run sites, data visualizations often featured information from multiple content areas. For example, a single program on global climate change might cover datasets on land, ocean and within the atmosphere. Content categories were devised in consultation with NOAA Education staff. The content categories were based on the categories within the library of datasets maintained by NOAA, with the knowledge that data collectors may have prior familiarity with the dataset categories. Climate and climate change were not an explicit categories, and those visualizations were categorized by data collectors into the content category that was the closest match. Data collectors were encouraged to note all content categories that might apply when observing a visitor/sphere interaction. Ocean-related content was the most common (32%), followed by astronomy content (29%) and atmospheric content (25.6%). Table 9 further details these results.

Table 9: Content Area

Content	Percent*	Frequency
Ocean	32.0%	221
Astronomy	29.1%	201
Atmosphere	25.6%	177
Land	20.5%	142
Frozen	10.9%	75
Earth Our Only Home	6.5%	45
Energy Planet	6.4%	44
Footprints	4.2%	29
Blue Planet	2.3%	16
Coral Reef	2.2%	15

*Due to multiple responses, percentages total to more than 100%.

Over half the interviewees (59%) saw sphere programming that was on a continuous auto-run loop; another 3% saw an auto-run program that was set only to run at specific times. Just over 20% saw a facilitated program. The remaining individuals (17%) viewed sphere programming that was visitor- initiated (Table 10).

Table 10: Type of Presentation[2]

Social Group	Percent	Frequency
Auto-Run Continuous	59.0%	390
Facilitated	21.2%	140
Visitor initiated	16.5%	109
Auto-Run at intervals	3.3%	22
Total	100%	661

Findings

1) What does the literature say about the learning potential of visualization experiences like the sphere?

Visualizations have significant potential to support learning by overcoming some of the basic limitations of language-based instruction for abstract, metaphor-rich and model based concepts that are common in most of the natural sciences, including geometry and Earth systems Science. Previous research shows that visualizations can have a variety of positive impacts on

[2] The auto-run continuous category is used to denote spheres that were continuously running content through a set playlist, without facilitation or visitor choice. Facilitated presentations refer to sphere content presented by an in-person facilitator. The visitor-initiated category refers to sphere content that was initiated or chosen by a visitor, generally through a kiosk. The auto-run at intervals category refers to presentations that occurred at certain times of day, such as every 30 minutes or at set times such as noon, 1:30pm, etc.

learning that are directly associated with the comparative advantage of science visualizations themselves. For instance, visualizations can reduce the amount of effort required to solve problems (Larkin & Simon, 1987); they may support scaffolding and the construction of mental models (Schnotz & Bannert, 2003); allow learners to understand complex science topics more completely (Ainsworth & Loizou, 2003); and can enhance understanding of specific dynamic concepts when animated or simulated (Tversky, 2001).

Those benefits are what NOAA hopes to achieve through use of the SOS capabilities. The ability to enhance dynamic or process-based concepts is of particular relevance to Earth System Science and has been recommended as innovative educational tools to improve Earth System Science literacy in the American public (Barstow & Geary, 2002). A NOAA-funded study by TERC (Cambridge, MA) further specified new approaches for enhancing Earth System Science education using dynamic systems representations (simulations and animations), geospatial and global visualizations, and inquiry-based teaching and learning strategies (Barstow and Hoffman, 2007).

Over the course of the last 3 years, ILI has periodically reviewed the literature on data visualizations, especially as pertaining to informal learning. There is very little research done on the impact of the sphere in informal contexts, however there is a significant amount of literature on non-spherical data visualizations in formal learning environments, often sampling college or graduate students with multiple previous courses in the fields of science and math. These results provide little basis for understanding the impact of novel projections and data visualizations in informal learning settings, where viewers fall within many contexts, including different levels of knowledge, varying social groups, ages, genders, and ethnicities. Our staff have continued to discuss this gap in the literature; at the 2007 Gordon Research Conference on Visualization in Science and Science Education, Martin Storksdieck (2007) discussed the affordances and limitations of science visualization on learning and concluded that not enough learning research and evaluation is devoted to creating a deep understanding of visualization's impact on learning.

It is not only the informal learning field that is concerned with the lack of knowledge about visualization and its benefits to learning, but within the visualization field itself there is a concern that knowledge of how well visualization approaches work lags behind visualization technological developments. (Chen, Bishop, and Shi, 2005) In 1987, the NSF sponsored a special report on visualization of science (McCormick et al., 1987). The International Cartographical Association working group on visualization was formalized in 1995 as a Commission on Visualization, and can now be found in its current form as the Committee on GeoVisualization at http://geoanalytics.net/ica/. These scholarly efforts tend to focus on how to represent geospatial information and the integration of computational methods with visual representation, and the usability of these representations from an end-user point of view (MacEachren and Kraak, 2001). The efforts typically stop short of examining how visualization enhances user learning, especially among the more casual and leisure-oriented users who typically visit science centers and museums. For that reason, researchers and scientists made a call for research to determine the contexts within which geovisualization is successful. In their

2005 paper, Schratt and Riedl posit that spheres will eventually be the ideal media to view dynamic global phenomena.

It is not only literature on different types of visualization users (formal education, graduate students, museum visitors, etc) that needs to be updated. Multiple visualization specialists have noted that the cognitive theories that have been used for traditional 2D mapping and visualizations may not hold for three dimensional dynamic representations, and therefore new cognitive theory must be developed. (Slocum et al. 2001; Rapp and Uttal, 2006) The need for cognitive theory and user perspectives is included within a variety of outlines for future research agendas (Naps et al., 2003).

Many of the most current research issues in visualization-based learning might eventually also be of relevance to the sphere. While recommending caution in extrapolation of the results to sphere environments, the main current research issues in the larger visualization are:

- the role of dynamic representations or animations,
- comparisons of two dimensional versus three dimensional (on a screen) visualizations,
- immersive visual environs,
- user control,
- gender, and
- age.

While each of these issues is relevant to the sphere context in some way, the findings from studies examining the issues may not hold true for the sphere, as the physical presentation of the data on the sphere is substantially different from the test condition in most of these studies. Interpreting the literature in these different contexts is therefore tricky, as the situations may be different enough not to be relevant to the sphere. Research we felt may hold some relevance, if only to provide results common in non-spherical displays, is summarized below.

<u>Role of dynamic representations/animations</u>

Animations or dynamic representations have been studied by a number of individuals (Gershon, 1992; Slocum and Egbert, 1993; Patton and Cammack, 1996; Cutler 1998). These studies have reached little agreement on whether animated maps are more effective at supporting learning than non-animated maps. Morrison et al. (2000) in a meta-analysis of dynamic representation in maps, suggests that the available evidence supports the notion that animated maps are less effective in spatial learning that static ones, though they point out that small gaps in the animation frames (micro-steps) may decrease the effectiveness of dynamic representations in this situation. Slocum et al. (2001) note that the Morrison et al (2000) analysis was not based primarily on geospatial visualizations, which may skew the results. The vast majority of datasets for the sphere use some form of animations, so this research is relevant if inconclusive for sphere-based learning. The type of learning described in these studies is often navigational or spatial-memory based, and therefore the results may not apply to the types of datasets shown on the sphere.

Comparisons of two dimensional versus three dimensional visualizations

Several studies have addressed whether two dimensional or three dimensional visualizations support cognitive knowledge or skills gain. There have been a number of comparisons between two dimensional and three dimensional visualizations. The three dimensional visualizations in this case are seen on a computer screen and are thus not truly three-dimensional, but are represented as such on the screen. In a study by Wang, Chang, and Li (2007), undergraduates found the 3D environment to have more practical applications, though those applications were not defined. While the study did not see a significant difference in cognitive outcomes between 2D and 3D, they suggested that more research was needed, as the two test conditions likely influence students in different ways. Interpretation from screen-based results should be used with caution in reflecting on the results from 3D immersive environments studies such as this one.

Immersive visual environs

While some researchers have assumed that virtual environments represent a proxy for the real world in spatial cognition, research does not support that. Seeing items in virtual environments does not have the same effect on cognition as seeing those items in a real world environment (Moura and Riecke, 2009). These results are interesting to sphere-based displays, in that it implies that the sphere may allow for outcomes that flat-screen visualizations cannot.

User Control

Slocum and the other authors (2001) claim that geospatial dynamic representations are most effective when users are able to control and interact with the representation, though they provide no evidence for this claim within their discussion. Several institutions make use of visitor kiosks, and as mentioned in the review of evaluations below, visitors felt that the user control through kiosks helped support their learning.

Gender

Literature since Maccoby and Jacklin's seminal book *The Psychology of Gender Differences* (1974) posited that women are less proficient than men in spatial manipulation and rotation (mentally manipulating seen objects), two key issues in the understanding of data visualization. Other studies (Halpern, 1992, among many others) have gone on to document gender differences in spatial abilities and navigational tasks. After Waller's meta-analysis (1999), many projects have focused on increasing females' ability in this domain. One recent study has shown perhaps a different path, by changing the nature of the displays, rather than providing additional training. Researchers at Microsoft have documented that larger displays may be correlated with increased spatial abilities in women, without any additional training necessary (Tan, Czerwinski, and Robertson, 2006). Because documented gender differences in geovisualization are in spatial manipulation and rotation, issues that are not as pertinent in sphere-based visualizations, as well as the increased display size of the sphere, one could hypothesize that the sphere may be a better tool for erasing gender gaps in visualizations.

Age

Similarly, age has a number of correlations with ability to comprehend visualizations. In a study of navigation of a 3D electronic world, Sjolinder, Hook, Nilsson, and Andersson, suggests that adults age 60 and up take more time to complete tasks and have more difficulty creating configural knowledge than do younger adults and children. (2005) Spatial Memory and rotation ability declined with age, both factors in navigation of virtual worlds, but perhaps less relevant in sphere-based visualizations, as the cognitive load on both spatial memory and rotation abilities is not as large. In addition, the end outcome for these studies is on increase in spatial knowledge, which is also less relevant to the sphere context.

2) What evidence exists for the sphere's learning potential in previous evaluation studies conducted to date?

The evaluations, and subsequent network conversations during meetings, explored what types of display were most effective on the sphere. Visitors have articulated an interest in seeing local information on the sphere, either information related directly to their area or information about specific events, such as Hurricane Katrina (Apley, 2004). Institutions have tried various means to incorporate local content into a global projection, including using a "picture-in-picture" feature, where 4 separate detailed images are broadcast within a frame on the larger globe. The evaluations currently gathered do not contain any other information on the effectiveness of this feature.

These evaluations also articulated a number of issues surrounding the context of the sphere. An evaluation from the Science Museum of Minnesota (SMM) in July 2006 (Grack Nelson and Ellenbogen, 2006) established that without facilitation, visitors stay at the sphere for approximately 3.5 minutes. When benches are provided, visitors spend substantially more time, an average of over 8 minutes.

SMM evaluations also documented that the majority of sphere visitors did not tend to walk around the sphere, or view it from multiple angles. Visitors at SMM reported they found it confusing where to stand within the space in order to best view the sphere (Grack Nelson and Ellenbogen, 2006).

In both the SMM evaluation and in a 2004 evaluation at the Maryland Science Center, visitors voiced issues over the height of the sphere (Apley, 2004). Some visitors, especially children, found it difficult to see images in the higher regions of the sphere. These evaluations recommended making more use of the axis-tilt feature of the sphere.

The 2007 MSC (People, Places and Design Research, 2007) and SMM evaluations (Grack Nelson and Weinhagen, 2007) also addressed the topic of labels on the sphere. Visitors appreciated having labels, arrows on content and other supportive interpretation, and they expressed an interest in having the labels appear briefly and then fade out over time. In the SMM evaluation, visitors had a low interest in seeing the continents and oceans labeled.

MSC completed an evaluation focused specifically on kiosk use in conjunction with the sphere (People, Places, and Design Research, 2007). Kiosk users felt that the kiosk helped support their learning. However, in coding of responses to what was learned, evaluators were unable to document a difference in the responses of kiosk users and non-kiosk users.

When asked directly about learning, sphere users in these evaluations did report learning. The PREL evaluation at the Bishop Museum reported that the sphere supported curricular learning in fieldtrip situations (PREL, 2007). There was some evidence that children had more difficulty with understanding the visualizations on the sphere than the adults. In the MSC 2007 study, 20% of the children reported that the sphere was easy to understand, as compared to 56% of the adults.

One issue not explored extensively in the evaluations reviewed was the strength of connection of the sphere to related content within the exhibition or institution. A 2007 evaluation of the Tech Museum's sphere (Korn, 2007) recommended building stronger direct connections from the content on the sphere to other related exhibit or programmatic content.

Several of the evaluations explored the many ways visitors benefited from their experience at the sphere. The most in-depth exploration of outcomes was conducted at Maryland Science Center (Apley, 2004). In that evaluation, 6 outcome categories were articulated:

- Big Ideas,
- Mechanical Explanations,
- Visualization of global views,
- Visualization of time and scale,
- Visualization of significant events, and
- Particular facts and specific examples.

These concepts were reiterated in the Tech Evaluation (Korn, 2007). As described in the methods section, ILI built on and expanded these categories in developing the instruments and coding categories for the evaluation described in this report.

3) In what ways do visitors perceive that they have learned something "new" from their sphere experience? How do factors such as sphere site, presentation mode, and content influence visitors' perceptions?

Visitors' Perceptions of "Learning Something New"

During exit interviews, visitors were asked whether they felt they had learned something new when viewing the datasets on the sphere. In response, 71% (490 visitors) said they had learned something new. Twenty-eight percent reported learning nothing new.

If they felt they had learned something new, visitors were asked in an open-ended question to describe what they had learned. These qualitative responses were coded into categories based on the type of learning. Because of the wide variety of the content the visitors could have been watching, ILI developed a coding rubric that was largely content-independent. (See Appendix C for the coding rubric.)

Table 11: What did you learn?

In what way…	Percent	Frequency
Processes	31.7%	165
Specific Events or Human Impact	21.9%	114
Geographic Facts	20.5%	107
Data Awareness	9.8%	51
Unrelated	6.7%	35
Size and Scale	5.6%	29
Sphere Technology	3.5%	18
Stewardship	0.4%	2
Total	100%	521

Of those that reported learning something new, 32% described learning something that involved process-based information, including the cause and effect of various Earth-Systems phenomena (Table 11). Representative answers included:

> *Process of how a glacier melts.*
>
> *Surprised to learn how long to damp out waves, how fast waves propagate around the Earth.*
>
> *Complexity of ocean currents and global reach of tsunamis.*
>
> *Carbon dioxide levels increase 1% every year-never thought about it that way, so that was new. But they didn't talk about actionable items for me to take.*

Approximately 22% of those who learned something new reported they learned something about specific events or about directly human-related issues:

> *There is a great Pacific Garbage Patch.*
>
> *Tsunami stated from earthquake under water (near Sumatra); 100x stronger than Haiti earthquake.*
>
> *Air travel could cause rapid spread of serious disease like H1N1.*
>
> *Many fires in places I didn't think would have them like near rain forest.*
>
> *Now I understand why they were warning us about tsunami when I was in India-everything is interconnected. I also liked the real-time earthquakes because it challenges you to look for patterns.*

Over 20% of the individuals reported learning something new that was fact-based and primarily centered on geographic information. Responses in this category included:

I didn't know what isotherms were.

I knew water was a limited resource but not how much.

About coral, how they grow and bleach.

That the sun always has explosions happening on it.

I didn't know East and West Africa were once separated.

Tectonic plates move as fast as your nails grow.

That there are 62 moons around Jupiter; [I] thought there were only 12.

Approximately 10% of visitors who stated they learned something commented on learning about the process of data collection and scientific work related to collecting this data. Some of their comments included:

I learned about so many different ways to collect weather data.

How the weather is studied by using the ocean (buoys).

Read about LCROSS-didn't know it was two pieces, that it crashed into the moon, and flew through dust that came up.

How they [satellites] track; if you asked me you could tell someone all the satellites. travel latitude and longitude but this way you can really see it.

That scientists have collected so much data on Gamma Ray Bursts.

Approximately 5% of the responses to this question focused specifically on learning about issues of size and scale:

Earth is about the size of a dime when compared to SOS sun. (Compared to the Sun as the sphere.)

Venus looks larger and smaller depending on distance.

How much farther south the south pole is. Much farther away from anywhere else. Nothing down there.

Jupiter has a storm as big as Katrina all the time.

A small percentage (3.5%) of visitors responded to this question by reporting learning something new related to the technology behind the sphere. For instance, one individual stated, "*Also I was curious about the technology of this sphere so I was trying to figure that out.*"

ILI ran correlations and chi-squared tests to look for connections between learning and the other demographic data. There were no correlations between learning something new with age, ethnicity, social group or seeing the sphere for the first time. Individuals of all ages, ethnicities and social groups were just as likely to report they learned something new. Those who had seen the sphere before were just as likely as those who had not to report they had learned something new. Women were more likely to state they had learned something new ($\chi^2(2, N = 674) = 7.492, p = .024$). This finding can be interpreted two ways. It is possible that women learn more from the viewing the sphere than men, or that women in general are more likely to report learning than are men.

Visitors' Perceptions of "New Realizations"

Prior to being asked whether or not they learned something new, visitors were also asked to complete the following stem sentence: "I never realized before…" This question was asked in an open-ended format and then answers were coded. As a check to ensure we had uncovered all possible outcomes visitors might experience, we asked both of these questions. During the development of the coding rubric, there was little substantive difference between the answers visitors gave to the question about something new they had learned and something they had never realized before. Therefore we used the same coding rubric for these two questions. (For Coding Rubrics see Appendix C.)

Table 12 below shows the range of new realizations visitors offered after their sphere experience.

Table 12: What did you never realize?

	Percent	Frequency
Geographic Facts	28.6%	165
Processes	26.0%	150
Specific Events or Human Impact	19.2%	111
Data Awareness	8.3%	48
Size and Scale	7.8%	45
Sphere technology	7.1%	41
Stewardship	2.4%	14
Other/Misc	0.5%	3
Total	100.0%	577

The most frequent answer (28.6%) was geographical fact-based information. These facts could include facts about the Earth or other planets' geography. Representative quotes included:

> *There are volcanoes on Mars.*
> *Earthquakes are constantly happening around the world.*
> *There really is a "Dark Side of the Moon"...Pink Floyd didn't just make that up.*
> *So little fresh water on the planet.*

The second most common answer made up just over a quarter of the responses (26%). These comments related to some sort of system-based thinking or cause and effect:

Tidal waves impact the ocean all over the world-they don't just impact the area in which they were generated.

Everything was so connected-oceans and weather.

Global warming distribution would be greatest (impact most) at the poles. I thought the climate change would be more uniform throughout the Earth.

Didn't know coral was so important, that it could bleach and that temp of water made such a difference to coral.

How magnetic field has changed overtime.

Nearly one-fifth (19.2%) of respondents mentioned either elements of specific events, such as the Tsunami of 2005 and Hurricane Katrina, or human-related impacts. Examples of these statements were as follows:

How little electricity used in North Korea.

Waves of the tsunami reached 35 ft. high.

It was a powerful demonstration of the extent of the Indian Ocean tsunami and how it impacted a lot of the world.

Didn't know there was a typhoon at the same time as Katrina.

Exactly how much energy Americans consume.

Just over 8% commented on the process of data gathering. This category includes realizations about satellites, buoys and other means how scientists gather data:

We have buoys all over the oceans taking measurements.

It takes the satellite to take 1 week of photo on the Earth.

Details of the lunar probes, how the data was collected.

Nearly 8% comments on how they had realizations related to size and scale. Some of those comments included:

The band of warm ocean water was so vast and I didn't realize it was connected to other bodies of water.

How far North America is. No wonder it's so cold!

Six miles down near Japan-I didn't realize that it [ocean] go that deep.

That the planet Jupiter is equivalent to 11 Earths across.

Seven percent of visitors commented on the sphere technology itself. Representative comments included:

The design to utilize the shape of the sphere was intriguing

That you could project a seamless image on a curved surface using only 4 projectors. Too cool!

That sphere exists, great teaching tool for inquiry.

Just over 2% of the interviewees commented on planet stewardship issues:

The propaganda was strong - on climate change. They have stopped calling it global warming probably because it keeps snowing during their conferences!
Poles are in such dramatic trouble; methane is going to be a huge problem as permafrost melts.

Factors Influencing Visitors' Perceptions

Visitors' perceptions of having learned something new varied significantly by sphere site ($\chi^2(30, N = 689) = 86.02, p = .000$).

Table 13: Percentage of Visitors Reporting Learning Something New by Institution

Did you learn anything new?	Yes	No
Bishop Museum	80%	20%
Boonshoft Museum of Discovery	84%	16%
Clark Planetarium	64%	36%
Hatfield Marine Science Center	56%	44%
\`Imiloa Astronomy Center of Hawai\`i	77%	23%
Lawrence Hall of Science	64%	36%
McWane Science Center	100%	0%
Maryland Science Center	59%	41%
Museum of Science and Industry, Chicago	74%	26%
North Carolina Aquarium	56%	44%
National Museum of Natural History	80%	20%
National Renewable Energy Laboratory	72%	28%
National Zoological Park	87%	13%
Science Museum of Minnesota	53%	47%
The Tech Museum	88%	12%
The Whitaker Center of Science and the Arts	38%	62%

Presentation mode also influenced visitors' learning perceptions. In fact, the differences by institution were likely partially due to differences in presentation mode, especially in facilitation. As illustrated in Tables 14 and 14, 87% of visitors who had a facilitated sphere experience reported learning something new, while 66% of visitors who experienced the other presentation modes reported similar results (see Table 14). The difference in visitor perception between these sphere experiences is statistically significant ($\chi^2(2, N = 689) = 22.31, p = .000$), meaning that visitors who participated in *facilitated* sphere experiences were more likely than those at all the other types of sphere experiences (auto run, auto run at intervals, and visitor-initiated) to perceive that they had learned something new. This finding is especially worth noting in the future funding of sphere-based presentations.

Table 14: Learned Something New Crossed with Presentation Modes

	Yes	No	Total
Facilitated	87.6% (n=121)	12.3% (n=17)	138
Auto-run	68.0% (n=264)	32.0% (n=124)	388
Auto-run at Intervals	77.3% (n=17)	22.7% (n=5)	22
Visitor-Initiated	63.9% (n=69)	36.1% (n=39)	108
Other	(n=1)	(n=11)	12

Table 15: Learned Something New Crossed with Facilitation

	Yes	No	Total
Facilitated	87.6% (n=121)	12.3% (n=17)	138
All other forms averaged	66.2% (n=351)	33.8% (n=179)	530

While facilitation clear is one of the factors influencing learning at individual sites, there are many other variables involved, and facilitation alone does not account for learning. None of the data at the Tech Museum were collected during facilitated presentations, yet 88% of the visitors reported learning something new from their SOS experience. Certainly the picture is far more complex than a single correlation. Note that the amount of facilitated programming here does not refer to the percentage of facilitated programming that these institutions present overall, but how much of the data collected at that site was during facilitated programming. So while facilitation correlates with visitors' perceptions of learning, it is not the sole determining factor.

Table 16: Percentage of Visitors Reporting Learning Something New & Amount of Facilitation

	Reported Learning Something New	Amount of Facilitated Programming
McWane Science Center	100%	92%
The Tech Museum	88%	0%
National Zoological Park	87%	48.9%
Bishop Museum	80%	62.2%
Boonshaft Museum of Discovery	84%	44.3%
National Museum of Natural History	80%	0%
`Imiloa Astronomy Center of Hawai`i	77%	2.1%
Museum of Science and Industry, Chicago	74%	7.7%
National Renewable Energy Laboratory	72%	17.2%
Clark Planetarium	64%	0%
Lawrence Hall of Science	64%	0%
Maryland Science Center	59%	27%
Hatfield Marine Science Center	56%	0%
North Carolina Aquarium	56%	6.3%
Science Museum of Minnesota	53%	0%
The Whitaker Center of Science and the Arts	38%	16.7%

Finally, sphere content also influenced visitors' perceptions of having learned something new from their sphere experience. Data collectors made note of which content categories visitors viewed during their sphere experience. The content categories on the interview instrument were based roughly on the categories used within the SOS library of visualization maintained by NOAA. As visitors experienced the sphere, it was possible for them to interact with one or more of multiple content categories, such as both ocean and atmosphere as part of their experience.

To understand how variations in sphere content influenced visitors' perceptions of learning, ILI researchers correlated visitors' perceptions of having learned something new with the content that they saw during their sphere experience to uncover potential relationships. Visitors who saw atmospheric datasets were significantly more likely to report learning something new than visitors who did not see that content. One potential interpretation of this finding is that visitors may know less about atmospheric content, and thus feel they learned more from their sphere experience. (Atmospheric content $\chi^2(2, N = 689) = 16.37, p = .000$). While visitors viewing other content topics did feel they had learned something new, there were no correlations with that particular content subject. There may be strong interaction effects in terms of learning between the type of content shown, whether the content was facilitated, and other variables but the nature of this data set did not allow further exploration of those potential relationships.

4) Which learning outcomes do visitors feel best describe their experience with the sphere? How do factors such as sphere site, presentation mode, and content influence visitors' selection of learning outcomes?

Visitors' Selection of Learning Outcomes

As described in the Methods section, through a process of reviewing all of the previous evaluations and consulting with NOAA and the SOS network, ILI researchers developed a set of 14 potential outcomes visitors might experience when seeing the sphere (see Table 16 below for the 14 outcomes). Visitors were shown these 14 statements, and asked to choose three that best reflected their sphere experience and to rank those three by marking first, second and third.

Table 17 shows the frequency with which each outcome was ranked in the top 3 by visitors. This analysis shows that the outcomes that were most salient for visitors were those that focused on the realism of the sphere, and in particular how it emphasizes complexity and change in Earth (or other planetary) Systems.

Table 17: Percentage that Ranked these Outcomes 1, 2, or 3

Overall Outcome	Percentage of Visitors
I appreciated how realistic the information appeared when on the sphere.	36.0%
The sphere helped me visualize specific events.	30.9%
It helped me to visualize certain concepts of time and scale.	24.9%
I learned or was reminded that the Earth is always changing and evolving.	22.6%
It made me think about the complex interrelations in Earth Systems.	22.6%
I was amazed at the beauty of what was shown on the sphere.	22.3%
The sphere helped me understand global processes.	21.3%
I felt a sense of the vastness of Earth.	17.9%
I felt a need to take better care of Earth.	17.1%
The sphere helped me better understand geography of Earth or other planetary objects.	15.9%
I felt a sense of how small Earth is compared to the greater universe.	12.9%
I felt a sense of the sacred in regards to Earth.	7.2%
I became interested in where the information on the sphere comes from.	6.8%
I was thinking about how this planet is my home.	6.4%

As seen in Table 17, over a third of the visitors stated that it was the realism of the data on the sphere that stayed with them, and nearly a third commented that the sphere helped them visualize specific events. Visitors also commented that the sphere helped them with aspects of time and scale. As one visitor commented "*I can see the time lapse, how things change over time*." While not discounting the reaction of the beauty of the sphere (nearly a quarter of the visitors mentioned this aspect), the main set of statements reflect the visualization and synthesis of events and systems. Least common were the more affective statements about the Earth or content, such as attachment to the Earth as home, or a religious or spiritual connection with the planet.

To examine potentially subtle trends within visitors' rankings, ILI researchers analyzed each statement according to how many visitors chose it first, second, or third. Table 18 illustrates these results. More visitors ranked "The sphere helped me visualize specific events" third than ranked it first; overall it was the second most common outcome.

Table 18: Outcome Rankings by Number of Individuals

Outcome	Ranking			Overall
	First	Second	Third	
I appreciated how realistic the information appeared when on the sphere.	106	84	59	249
The sphere helped me visualize specific events.	64	69	81	214
It helped me to visualize certain concepts of time and scale.	55	59	58	172
I learned or was reminded that the Earth is always changing and evolving.	31	59	66	156
It made me think about the complex interrelations in Earth Systems.	41	60	55	156
I was amazed at the beauty of what was shown on the sphere.	65	48	41	154
The sphere helped me understand global processes.	28	54	65	147
I felt a sense of the vastness of Earth.	56	33	35	124
I felt a need to take better care of Earth.	64	26	28	118
The sphere helped me better understand geography of Earth or other planetary objects.	32	39	39	110
I felt a sense of how small Earth is compared to the greater universe.	30	31	28	89
I felt a sense of the sacred in regards to Earth.	21	17	12	50
I became interested in where the information on the sphere comes from.	6	15	26	47
I was thinking about how this planet is my home.	14	17	13	44

Factors Influencing Visitors' Selection of Learning Outcomes

To understand the ways in which various factors influenced visitors' selection of learning outcomes, correlation analyses were conducted. Those analyses revealed several trends which are reported below, first according to each individual outcome statement and then looking at factors across learning outcome statements.

I appreciated how realistic the information appeared when on the sphere.
Males were more likely to rate this outcome in the top 3 than were women ($\chi^2(1, N = 674) = 9.50, p = .002$).

The sphere helped me visualize specific events.
While age significantly correlated with this outcome, no one clear age trend was evident (χ^2(7, *N* = 691) = 15.39, *p* = .031).

It helped me to visualize certain concepts of time and scale.
Visitors who saw a facilitated presentation were more likely to rate this outcome in the top 3 than were those who saw some other type of presentation (χ^2(1, *N* = 691) = 6.73 *p* = .010).

I learned or was reminded that the Earth is always changing and evolving.
This statement was more likely to be rated in the top 3 by those who saw a facilitated presentation (χ^2(1, *N* = 691) = 5.77 *p* = .016) and those visitors above age 50 (χ^2(7, *N* = 691) = 16.53, *p* = .021).

It made me think about the complex interrelations in Earth Systems.
This statement was more likely to be rated in the top 3 by visitors above age 50 (χ^2(7, *N* = 691) = 16.69, *p* = .019)

I was amazed at the beauty of what was shown on the sphere.
Females were more likely to rate this outcome in the top 3 than were males (χ^2(1, *N* = 674) = 4.518, *p* = .034).

The sphere helped me understand global processes.
This statement was more likely to be rated in the top 3 by those visitors above age 50 (χ^2 (7, *N* = 691) = 18.76, *p* = .009).

I felt a need to take better care of Earth.
This outcome was slightly more likely to be reported by visitors of Asian/Pacific Islander ethnicity, though the sample size per cell in this category was small enough to make this finding less certain (χ^2(6, *N* = 690) = 21.02, *p* = .002).

The sphere helped me better understand geography of Earth or other planetary objects.
Males were more likely to rate this statement in the top 3 than were women (χ^2(1, *N* = 674) = 4.10, *p* = .043).

I felt a sense of the sacred in regards to Earth.
Visitors who saw a facilitated presentation were more likely to rate this outcome in the top 3 than were visitors who saw one of the other presentation formats (χ^2(1, *N* = 691) = 3.88, *p* = .049).

I was thinking about how this planet is my home.
Visitors who saw a facilitated presentation were more likely to rate this outcome in the top 3 than were visitors who saw one of the other presentation formats (χ^2(1, *N* = 691) = 7.54, *p* = .006).

None of the statements correlated by first time viewing or with social group.

One goal of this study was to investigate whether certain types of visitors, or certain types of sphere contexts, correlated with certain outcomes. While this study was not designed to establish causation, these correlations provide grounds for further investigations. To run the correlations, the outcomes were divided into two categories, either chosen and ranked by the visitors (i.e. either ranked 1, 2, or 3), or not picked by the visitors. Only significant correlations (at the $p = .050$ level or higher) are reported here.

The potential impact of facilitation

Visitors who saw a facilitated show were both more likely to report they had learned something new, and were more likely to have slightly different outcomes, particularly in terms of visualizing certain concepts of time and scale, understanding that the Earth is always changing and evolving, and in terms of the more affective outcomes, sacredness and need to care for the Earth.

Gender

Males were more likely than females to pick outcomes related to the realism of the information and how the sphere helped them better understand geography. Females were more likely to pick the outcome "I was amazed by the beauty of the sphere" than males.

Age

Certain outcomes such as "I learned or was reminded the Earth is always changing and evolving" and "It made me think about the complex interrelations in Earth Systems" were more likely to be picked by visitors over age 50 than those under age 50. This is an interesting finding, as in the literature review detailed above, studies show older adults have less spatial capabilities than younger adults. It is possible that the sphere requires less cognitive load to process the information shown than a visualization that needs to be manipulated, that still would not explain why older adults are more likely to pick these outcomes.

Repeat viewings

The outcomes chosen by visitors seem to hold over repeated viewings of the sphere. During the SOS collaboration meetings, some discussions had focused on whether viewers might have one immediate reaction, such as an appreciation of beauty, upon first viewing of the sphere and then have another set of reaction upon further viewing. The correlations above do not support that concept, as there were no differences in any of the outcomes by whether it was an individual's first viewing or a repeat viewing.

5) In what ways do visitors perceive that the sphere's 3-D presentation of information influences their learning?

Within the scope of this study, NOAA and ILI were interested in exploring whether visitor perception of data visualizations is changed by seeing it on the sphere. In this particular study, we did not include a test condition or comparison of the same visualization in a two-dimensional format. Instead, we measured only visitors' perceptions of what was unique about the way in which the sphere information was presented, and how that presentation may have contributed to their learning. The decision was made to use the term "information" rather than "data visualization" due to a concern that visitors may not understand data visualization terminology.

When visitors were asked whether the way in which information was presented on the sphere changed how they understood that information, 82% said yes, seeing it displayed on a sphere changed their understanding of the information. As one visitor said: "*Anytime you can see 3D, it's easier to grasp concepts of currents, airflow and systems. It helps kids especially to understand the concepts*." Other visitors commented that "*A flat map doesn't give the real scope of how sea level affects the world"* and *"It brings it to life."*

The remaining 18% of visitors felt that the way in which the information was presented on the sphere did not influence their learning. They made comments such as the following:

> *Spent time teaching kids and explaining things to them.*
>
> *Was paying more attention to keeping track of kids.*
>
> *I don't think I was able to spend enough time.*
>
> *Presenting the information that I knew. Presented on the sphere it drew me in to it and kept me to watch it.*

Table 19 shows the range of responses in terms of what exactly visitors felt was different about seeing information on a sphere.

Table 19: In what way does seeing the information on the sphere change the information?

In what way…	Percent	Frequency*
Provides perspective	206	29.8%
Visual	165	23.9%
Enhance information	108	15.6%
Multi-dimensional or 3D	91	13.2%
Makes realistic	84	12.2%
Uncodable	33	4.8%
Did not change understanding of information	115	16.6%
Total	691	

*Some responses were coded into multiple categories, therefore totals add to more than 100%.

The most common comment (29%) was that the sphere provided additional perspective not available in other ways. As visitors stated:

> *[It] Helps you see exactly where things are in relation to everything else.*

Absolutely. You can actually see the impact of things around the whole globe. Communicates information differently than just seeing it in the news.

Definitely. You get a better understanding of how things are interrelated.

Yes, makes info[rmation] clear, how do things line up; shows depth, more interactive than map. Draws you in.

Makes the information much clearer, gives you a different perspective.

Visitors repeatedly used variations of the word "visual" when describing the sphere. Nearly a quarter (23.9%) made comments emphasizing that concept:

I could see it – [I'm a] visual learner.

The visualization really helps me retain the information and holds my attention.

The sphere captures my attention and with live picture it makes for better visual. understanding. I would say better overall because I am a kinesthetic learner.

Absolutely-very visual; could see interaction between things like water and air.

Multimedia-like virtual reality provides entire understanding; intuitive, direct, gives dimension.

Yeah, visual representation neat versus flat surface; new way to look at it almost like an "actual view".

The multi-dimensional or 3D nature of the sphere was mentioned by 13% of the interviewees:

The sphere allows for more realistic 3D mapping of astrophysical phenomena.

I look at that stuff (weather, satellite, water vapor) on the web all the time but it's cool 'cause it's round instead of flat.

It provides the information in a 3Dway - makes it more viewable.

Twelve percent of the visitors stated that seeing the information on the sphere made it seem more realistic:

It makes it seem more real/tangible. Plus can see the planets from every side by walking around.

I feel more involved, much more intimate interaction.

Makes it more real; more pertinent, not just a number on a piece of paper, more tangible.

It's more realistic but also gives me more context to better understand the information like weather and stuff.

The element of realism is so important on a map there is so much distortion and misperception. This allows you to see the connection, interactivity of things.

In analysis, we performed statistical cross-tabulations with the demographic and social group information gathered for visitors. Neither gender, ethnicity, age, nor social group were factors in visitors' perceptions of how the sphere information was presented. Visitors who had seen the sphere before were just as likely to report that seeing the information on the sphere changed their understanding of the information as visitors who were seeing the sphere for the first time.

Conclusions

With funding from NOAA, ILI completed this multi-site summative evaluation of Science on a Sphere®. The sphere is an innovative way to visualize data and prior evaluations reported users react in very different ways, from curiosity about how the data in the visualizations are gathered to a sense of wonder about the vastness and the complexity of Earth. The goal of ILI's evaluation was to explore visitors' perception of outcomes based on their experience with the sphere, to define a set of outcomes that occur most commonly, and to generate hypotheses for exploration in further research.

The prime method for collecting data was visitor interviews post-sphere experience. Interviews at most of the sphere sites were conducted by the on-site staff. ILI collected data at four of the sites, chosen based on greatest need of data collection support. Visitor interviews began with open-ended questions on what visitors had realized by seeing the sphere, how seeing information on the sphere was different than seeing it in other ways, and what, if anything they learned through seeing the sphere. After completing those questions, visitors were asked to read a series of 14 possible outcomes, and choose and rank three that most closely described their experience. The development of the rank-based outcomes stemmed from the initial review of prior evaluations of the sphere. During the review, all potential outcomes mentioned within the evaluations were gathered. ILI then went through a process of examining and clarifying each outcome in consultation with NOAA Education staff and the larger SOS network. As this was a study designed to generate a reliable and valid set of outcomes for the sphere, outcomes that were collected in the open-ended format were coded, and compared to the close-end outcomes to ensure that an exhaustive set of outcomes was created. These outcome categories should be used for other studies.

The final sample included 691 data points from 16 sphere sites. While the intention was to gather data from as many sites as possible, some SOS sites were not included. Under careful consideration, we excluded certain facilities from the study. For example, some sites were excluded from the sample based on their very recent installations of the sphere, as they were still fine-tuning the format and display options. Some visitor center-base spheres, such as the NOAA Earth System Research Lab, the NASA Goddard Space Flight Visitors Center, and NOAA's National Severe Storms Laboratory, declined to provide data on the grounds that their sites were too dissimilar to the other SOS sites. Still other sites were requested to submit data but did not do so.

The sites for the sphere varied in a large number of ways. The final list of sample SOS sites represented a variety of geographic locations, a range of audience populations and numbers, and a variety of sphere presentations types. All but one of the sites were informal science learning sites. Many institutions were primarily science focused, but others such as the Whitaker and the 'Imiloa Astronomy Center also had strong arts and culture components. There was significant variety in how each of the spheres was placed within the site. Some of the spheres were situated within a theater; some spheres were placed in a lobby setting. Some spheres were integrated within a specific exhibit, and the exhibit and SOS content were designed in an integrated fashion. Each of these contexts was represented within this sample.

In addition to the differences of location and context of the sphere placement, there were substantial differences in the presentation of the sphere from site to site. At some sites, a facilitator or docent presented the datasets on the sphere at set times, others ran an automated set of data visualizations that play in a loop on the sphere. There were a few sites that ran data visualizations or other content on the sphere through visitor-initiated actions, such as through a kiosk.

Within the sample of interviews collected, eighty percent of those sampled were seeing the sphere for the first time; the remaining twenty percent had seen the sphere one or more times. Roughly half were men and half women. A range of ages was included, with the most common age category being age 40-49. (Only adult data was collected, therefore these percentages do not reflect youth viewing.) Ocean-related content was the most common (32%) content viewed, followed by astronomy content (29%) and atmospheric content (25.6%).

The results of this evaluation are framed around five questions:

1. **What does the literature say about the learning potential of visualization experiences like the sphere?**

ILI performed a literature review to determine whether results from other related fields could be used to contextualize the findings from this evaluation study. The literature review resulted in three main findings. First, geovisualization and related fields face some of the same current issues as the sphere. Those fields are currently investigating the impact of the following variables on learning:

- the role of dynamic representations or animations,
- comparisons of two dimensional versus three dimensional (on a screen) visualizations,
- immersive visual environs,
- user control,
- gender, and
- age.

Secondly, while there is a significant amount of literature these issues in data visualizations, the vast majority of it currently applies to either formal learning environments or to screen-based visualizations. These results provide little basis for understanding the impact of three-dimensional projections and data visualizations in informal learning settings, where viewers fall within many contexts, including different levels of knowledge, varying social groups, ages, genders, and ethnicities. As other fields begin to incorporate sphere-like interfaces, these fields of study may become more relevant to the SOS network. In Appendix A, ILI has suggested some key resources to consider monitoring for future relevant work.

Third, multiple visualization specialists have noted that the cognitive theories that have been used for traditional geo data visualization do not transfer to three dimensional environments. The technology for visualization has outpaced the theoretical development in this field, and therefore new cognitive theory must be developed. (Slocum et al. 2001; Rapp and Uttal, 2006, Naps et al., 2003) ILI suggests that this finding, also applies to SOS. We would suggest investigating geovisualization on the sphere along with more traditional visualization methods to build more of a foundation for comparison of studies.

2. What evidence exists for the sphere's learning potential in previous evaluation studies conducted to date?

ILI researchers reviewed prior evaluations of the sphere, in an effort to better understand the nature of learning with the sphere, what previous studies had accomplished, and to ascertain any factors that may influence learning with the sphere, and ultimately to determine previously defined outcomes that may be relevant to this study. Of the 20 prior evaluations reviewed, all but one were front-end or formative evaluations, and thus most did not focus directly on learning outcomes. When those evaluations did ask directly about learning, visitors reported they were perceived they were learning from seeing the sphere. The Bishop Museum evaluation reported that the sphere supported curricular learning in fieldtrip situations (PREL, 2007). Several other evaluations explored the many ways visitors benefited from their experience at the sphere. The most in-depth exploration of outcomes was conducted at Maryland Science Center (Apley, 2004) and were echoed in the Tech Evaluation (Korn, 2007). In the MSC evaluation, six outcome categories were articulated: big ideas, mechanical explanations, visualization of global views, visualization of time and scale, visualization of significant events, and particular facts and specific examples. As described in the methods section, ILI built on and expanded these categories in developing the instruments and coding categories for the evaluation described in this report.

Best practices as represented by prior evaluations

While it was not the goal of this study to provide a guide to best practices in sphere settings, the evaluations do provide useful formative information for sphere facilities interested in best practices. One important finding was the increased visitor stay time when benches are provided. Evaluation also found that individuals do not tend to walk around the sphere, and the visitors' need to better understand where to best view the sphere. Visitors found labeling on the sphere to be helpful in understanding the content provided.

In other learning-based findings from the previous evaluations, there was some evidence that children had more difficulty with understanding the visualizations on the sphere than the adults. In the MSC 2007 study, 20% of the children reported that the sphere was easy to understand, as compared to 56% of the adults. A 2007 evaluation of the Tech Museum's sphere (Korn, 2007) recommended building stronger direct connections from the content on the sphere to other related exhibit or programmatic content.

3. **In what ways do visitors perceive that they learn something new from their sphere experience? How do factors such as presentation mode, sphere site, and content influence visitors' perceptions?**

Visitors felt they learned new information.

During exit interviews, visitors were asked whether they felt they had learned something new when viewing the datasets on the sphere. In response, 71% (490 visitors) said they had learned new something new. Twenty-eight percent reported learning nothing new. Of those that reported learning something new, 32% described learning something that involved process-based information, including the cause and effect of various Earth-Systems phenomena. Approximately 22% of those who learned something new reported they learned something about specific events or about directly human-related issues and over 20% of the individuals reported learning something new that was fact-based and primarily centered on geographic information.

The sphere supports understanding complex processes and phenomena.

Visitors were asked to rate a series of statements to choose the top three that best reflected their sphere experience. What emerged most often were statements that reflected the realism of the sphere, how it emphasized complexity and change in Earth (or other planetary) Systems. The results from the outcomes echoed visitor responses to other questions, that it was the realistic and visual nature of the sphere that best reflected their experience. When combining all the results, over a third of the visitors stated that it is the realism of the data on the sphere that stayed with them, and nearly a third commented that the sphere helped them visualize specific events. Visitors also commented that the sphere assisted them comprehend certain concepts of time and scale. While not discounting the reaction of the beauty of the sphere (nearly a quarter of the visitors mentioned this aspect), the main set of statements were about the visualization and synthesis of events and systems. Least common were the more affective statements about the Earth or content, such as attachment to the Earth as home, or a religious or spiritual connection with the planet. This suggests that the sphere supports deeper exploration, beyond simple fact-based knowledge, of this content matter and that by supporting process-based knowledge, it is specifically well suited for use in the interpretation of Earth system Science.

Facilitation correlates with learning.

While visitors who saw facilitated and unfacilitated presentations both reported learning new information, facilitation correlated strongly with visitors' perception of learning. Those visitors who saw a facilitated presentation were substantially more likely to state they had learned something new. Facilitation also correlated with specific outcomes, including: increased understanding of time and scale, increased understanding of constant change of the Earth and increased perception of the sacredness of the Earth and need to take care of it. In the future, NOAA should consider expanding facilitated programming efforts in conjunction with the sphere.

Learning varies by site.
Learning varied greatly by specific SOS site. While facilitation clearly had some influence on this variation, there were very likely a complicated set of compounding factors involved. We were not able to determine particular other factors that might account for this variation. Future studies at individual sites should probe this finding further to see if particular causes can be determined. In a 2007 study of the Tech Museum (Korn) it was recommended that stronger connections be made between the content shown on the sphere and content elsewhere in the institution as a means for supporting learning. In any future evaluations, the study should take into account whether supplementary related content in the institution supports the sphere content, in an effort to seek other correlations.

Learning may vary by content type.
ILI researchers correlated visitors' perceptions of having learned something new with the content that they saw during their sphere experience to uncover potential relationships. Visitors who saw atmospheric datasets were significantly more likely to report learning something new than visitors who did not see that content. One potential interpretation of this finding is that visitors may know less about atmospheric content, and thus feel they learned more from their sphere experience. While visitors viewing other content topics did feel they had learned something new, there were no correlations with that particular content subject. There may be strong interaction effects in terms of learning between the type of content shown, whether the content was facilitated, and other variables but the nature of this data set did not allow further exploration of those potential relationships. We would suggest further research into the types of content shown on the sphere.

4. **Which learning outcomes do visitors feel best describe their experience with the sphere? How do factors such as sphere site, presentation mode, and content influence visitors' selection of learning outcomes?**

One of the main goals of this evaluation was to develop a reliable and valid set of common outcomes stemming from visitors' sphere experiences. ILI developed a set of 14 outcomes based on conversations with NOAA staff, the SOS network, and prior evaluations. During the interview, we asked visitors to report what they hadn't previously realized and what they learned in their own words. We then asked visitors to identify and rank their sphere experiences based on the main set of 14 outcomes. The redundancy of expressing outcomes was purposeful, to ensure that the set of sphere outcomes was complete. Coding of the open-ended did not reveal any new outcomes. Based on this study, ILI can recommend the outcome set as defined within this study to be used in other sphere-based studies.

The most common outcomes visitors experienced when seeing the sphere were:

- I appreciated how realistic the information appeared when on the sphere.
- The sphere 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 on the sphere.
- The sphere helped me understand global processes.

As noted above, these outcomes tend to be the more concrete, cognitive, and process-oriented outcomes. More affective outcomes such as sacredness of the Earth and thoughts of the Earth as the home planet fell towards the very bottom of the list of outcomes that visitors experienced. As these outcomes were relatively uncommon, we would recommend trimming the outcome list of 14 to 8-10 outcomes based on this study. These are the key outcomes for understanding impact of spherical data visualizations. Future studies in spherical data visualization should concentrate on these key outcomes.

As noted in the People, Places and Design evaluation of SOS and the interpretative elements at Maryland Science Center (2007), individuals' perceptions of their increased learning does not always match documentation of that learning. A more controlled investigation in the future into documenting actual visitor learning to build on this result would be useful.

5. **In what ways do visitors perceive that the sphere's 3-D presentation of information influences their learning?**

   Visitors feel seeing information on the sphere is more realistic and provides more perspective. The great majority (82%) of visitors who view the sphere felt that seeing information on the sphere was significantly different than seeing it in other formats. They felt that the sphere provided a more realistic, and more visual experience, that it enhanced information and provided greater perspective. Visitors felt that the multi-dimensional aspect of the sphere added to their viewing and used the terms 3D, Real, Perspective and Visual, when describing the elements of their sphere experience. In ranking their outcomes, the most common outcome visitors had was appreciating the realism and lack of distortion of the information shown on the sphere.

   In analysis, we performed statistical cross-tabulations with the demographic and social group information gathered for visitors. Neither gender, ethnicity, age, nor social group were factors in visitors' perceptions of how the sphere information was presented. Visitors who had seen the sphere before were just as likely to report that seeing the information on the sphere changed their understanding of the information as visitors who were seeing the sphere for the first time.

Recommendations for Future Studies

The study conducted here was a vast exploratory study, designed to document perceived learning, create and test an initial set of outcomes and to generate correlations worth researching in the future. While this study was designed to be a rigorous as possible under the conditions, the number of variables that could influence the results was extremely large. Now that a baseline set of outcomes across many sphere sites has been established, we would recommend future studies attempt to limit or control for the number of potentially confounding variables. These studies would likely be based at a much smaller number of sites, even a single site, under carefully controlled circumstances. We would recommend further exploring the following issues:

1. The impact of facilitation

Within this study, facilitation correlated very strongly with visitor's perception of their learning, yet there were clearly other compounding variables involved which could not be identified. We would recommend that NOAA examine this issue closely by holding the content, age, and setting of the visualizations stable and varying only whether the presentation was facilitated.

2. Two-Dimensional versus Three-Dimensional Presentation Systems

Visitors claim that seeing visualizations on the sphere was different than seeing those visualizations in other ways. However, we did not present the visualizations through other presentation systems to present a true comparison. The comparison of SOS to other scientific data visualization methods is critical for the understanding of the benefits and affordances of the Science on a sphere tool. This would allow NOAA to begin to address the question of which type of content is most effective on a sphere as opposed to other display techniques. We suggest a controlled research study focusing on middle school field trips at 2-3 of the SOS sites. The research question is: Under which conditions is SOS a more effective tool for presenting data visualizations than flat-screen data visualizations? The three test conditions would be:

1. The sphere, as developed by NOAA;
2. The image of a sphere as projected onto a flat screen (such as shown by Google Earth); and
3. A flat-screen visualization of the data, (i.e. the sphere "unwrapped").

Testing in three states allows us to research the relative benefits visualization of scientific data via the projection method onto a physical sphere versus a flat-screen representation of a sphere or a flat-screen visualization without a sphere. This will require utilizing flat-screen equivalents of the Earth Sciences sphere content, in order to keep the content stable across the three test conditions.

3. Controlled studies on content

Within this study, individuals who saw atmospheric datasets were more likely to report learning than those that did not. There are number of reasons that this could occur, including that the sphere is uniquely capable of supporting visitors' learning of atmospheric content. However, it could also be true that visitors simply know less about this particular type of content and thus any information presented, whether on the sphere or otherwise, helps increase their learning. A study on atmospheric learning should assess visitors' incoming knowledge as well as their post-experience knowledge and compare any resultant change to changes in learning from other content categories.

4. Perceived versus actual learning

Due to the range of types of content under examination within this study, we were only able to assess perceived change in learning, based on visitor self-report. Future summative studies for individual sites and programming should develop learning goals. If those goals are related to cognitive knowledge gain, indicators of learning should be developed and tested with visitors prior to and after their sphere experiences. This type of study would reaffirm the finding here that learning occurs.

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Appendix A: Key Visualization References

While the above findings may apply tangentially to SOS, if at all, the academic literature is changing rapidly on visualization, and we suggest monitoring a number of journals for future developments in this field. Suggested journals, roughly in order, are:

- Computers & Geosciences
- International Journal of Geographic Information Science
- Cartography and Geographic Information Science
- Information Visualization

Further, we would recommend reviewing Gilbert, Reiner and Nakleh's 2008 book Visualization: Theory and Practice in Science Education. Later this year in the same series (Models and Modeling in Science Education) Phillips, Norris and Macnab are due to publish *Visualization in Mathematics, Reading and Science Education* which may also be useful.

Gilbert, John K.; Reiner, Miriam; Nakhleh, Mary (Eds.) (2008). Visualization: Theory and Practice in Science Education in Models and Modeling in Science Education, Vol. 3. Springer Publications, New York.

Phillips, Linda M., Norris, Stephen P., Macnab, John S. (2010). Visualization in Mathematics, Reading and Science Education in Models and Modeling in Science Education, Vol. 5 Springer Publications, New York.

Key conferences in the technology and geovisualization world include:

- IEEE Visualization
- EuroVis
- SIGGRAPH
- Gordon Research Conference on Visualization in Science & Education

Further Penn State maintains a center called GeoVista, whose works could be relevant to future Science and the sphere efforts.

Date:______________	❑ Weekday ❑ Weekend	
Interviewer: _________	Visitor # ____	Site:_______________

Content shown: ❑ Atmosphere ❑ Land ❑ Ocean ❑ Astronomy ❑ Footsteps
❑ Other: __________________

Presentation type: ❑Facilitated (staff/docent) ❑Auto Run ❑ Visitor-initiated

Comments on visitor behavior:

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1. Is this the first time you have seen the Sphere? ❑ Yes ❑ No

2. In relation to the Sphere presentation you just saw, please complete the following sentence:

   One thing I never realized was that…..

3. Does seeing information on the sphere change how you understand it? In what way?

4. Based on what you know about this topic or topics from before you saw this presentation,
   a. Did you learn anything new? ❑ Yes ❑ No
   b. If "yes", tell me something you learned.

We’re almost done. **(Hand the clipboard to the visitor)**

5. Still thinking about your experience with the Sphere….

- Please read each statement below.
- Choose the 3 statements that best reflect what you got out of your experience with the Sphere.
- Then rank those 3 statements with #1 being the most important to you, #2 the second most important, and #3 the third most important.

Your reaction to the Sphere:

a. ______ I felt a sense of the vastness of Earth.
b. ______ I felt a sense of how small Earth is compared to the greater universe.
c. ______ I felt a sense of the sacred in regards to Earth.
d. ______ I felt a need to take better care of Earth.
e. ______ I was thinking about how this planet is my home.
f. ______ I was amazed at the beauty of what was shown on the Sphere.
g. ______ I appreciated how realistic the information appeared when on the Sphere.
h. ______ I learned or was reminded that the earth is always changing and evolving.
i. ______ It helped me to visualize certain concepts of time and scale.
j. ______ It made me think about the complex interrelations in earth systems.
k. ______ I became interested in where the information on the Sphere comes from.
l. ______ The Sphere helped me visualize specific events.
m. ______ The Sphere helped me better understand geography of Earth or other planetary objects.
n. ______ The Sphere helped me understand global processes.

NOW WE JUST HAVE A FEW QUESTIONS ABOUT YOU AND YOUR GROUP.

7. Who did you come here with today?

❒ Alone ❒ With friends or family ❒ In an organized group

8. <u>Not including yourself</u>, please indicate how many people you are visiting the museum with today, in each category.

0-6 years old ________ people
7-12 years old ________ people
13-17 years old ________ people
Over 18 years old ________ people

9. Including today, how many times have you been to each of the following in the last 12 months?

This exhibit ________ times
This museum/institution ________ times
Other museums, aquariums, nature or science centers ________ times

10. Gender: ❒ Male ❒ Female

11. What year were you born? _________________

12. Ethnicity: ❒ Asian, Indian or Pacific Islander
❒ Black or African American
❒ Hispanic/Latino
❒ American Indian/ Alaskan Native
❒ White
❒ Other (specify): ___________________

Thank you for your time! Your feedback helps us create better exhibits.

Appendix C: Coding Rubrics

Science On a Sphere® Site Interview
Coding Categories

Q2 One thing I never realized was that...
Q4 Did you learn anything new....

Category	Definition	Example
1. Geographic Facts	The sphere helped me better understand geography of Earth or other planetary objects. References to general geographic features (Earth or other planets).	Coral reefs exist only in a certain part of the hemispheres; There's a Caribbean plate. So little fresh water on the planet.
2. Processes	Planetary processes and systems. References to global processes (atmosphere, land, water), interactions (facts) and impacts (climate). Implies action over time; cause and effect.	Glaciers are melting fast; How storms join together so quickly; How active oceans are; How much water is locked up in the mantel.
3. Events	The sphere helped me visualize specific events. References to realizations related to specific visualizations of data (energy use, human impact, cultural and historical context, animal research).	How "lit up" Western Europe is; Didn't know there was that much air traffic; Turtles follow temperature gradient;
4. Data Awareness	I became interested in where the information on the sphere comes from/ how it is used/Awareness of data. References to who, how or why scientific data is collected and used.	Meteorologists use this data to forecast the weather.
5. sphere technology	References to how data was projected onto sphere.	Was watching son try to figure out how pictures were presented; How the projection works
6. Scale	References to scale (size, time, distance) comparison of planets, geographic features, or events.	How close the North American continent is to Europe; I was so far away from Africa;
7. Stewardship	References to conservation, behavior change, environmental action. Not simply climate change, but what humans can/should do	

8. Nothing/Don't know		Didn't have a lot of time to absorb-watching child; Nothing-I wasn't sure exactly what the colors meant; Just looked, didn't really take much in.

Q3. Does seeing information on the sphere change the way you understand it? In what way?

Category	Definition	Example
1. Provides perspective	References to context, scope, relation of information.	Seeing the whole globe provides "whole perspective"; Puts it into dimension. Gives perspective of whole not just your area; Get a bigger picture of information [turtle migration]; Because you can see where in world in relation to where you are - same phenomenon in different places when you walk around; It's easier to comprehend, to grasp. Like the amount of fresh water, you could see how much it gave perspective; Bigger scope, see it on a bigger scale, see the whole world
2. Enhances information	References to definition, clarification, emphasis, and reinforcement of information presented.	Explains population - seeing Europe lit up really emphasized the population compared to North America.; Clarifies the extent and depth of info; Defines information better; to see how currents work - seeing lights go on = aware of where energy is being used; So graphic, enables you to see lots of details.
3. Makes realistic	References to information being active, “coming to life”	"More real" and understandable than when scientists talk or what you read in books; Heard about El Nino; saw that phenomenon, what it actually looks like; Just seeing how the plates, how they collide and pull apart and the earthquake activity it causes; Visual of complete picture of moon makes it more real; The size, [its] realistic-more than just a globe; Uniqueness= context for where things are on the planet
4. Multi-dimensional	References to 3D presentation on its own or in combination with other audio/visual (flat screens).	Anytime you can see 3D = easier to grasp concepts of currents, airflow – systems; Easier with combination of in the round presentation and narration; 3D=can see what is going on with weather patterns-don't get that with smaller globes; 3D=can see how everything interacts around the world-very cool; 3D makes it more representational, relevant; You really think of it as the world, and because it revolves, it gives you a better understanding of its "worldness" than over a flat screen.
5. Visual	References to ease of	Visual is always better. It depends what is on

4. Multi-dimensional	References to 3D presentation on its own or in combination with other audio/visual (flat screens).	Anytime you can see 3D = easier to grasp concepts of currents, airflow – systems; Easier with combination of in the round presentation and narration; 3D=can see what is going on with weather patterns-don't get that with smaller globes; 3D=can see how everything interacts around the world-very cool; 3D makes it more representational, relevant; You really think of it as the world, and because it revolves, it gives you a better understanding of its "worldness" than over a flat screen.
5. Visual	References to ease of learning through visual presentations.	Visual is always better. It depends what is on there but you get to see the curve of places, perspective; It's just more visual. I can understand it better seeing it on the sphere; Visually dramatic; you can tell people something and it will go in and out, but if you visually show them, it sinks in and they register it; Visual representation neat vs flat surface; new way to look at it almost like an "actual view"; It's easier to see the Earth is a globe, you can visualize the change

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