

Local to Global: Using Science Visualizations to Improve Earth System Science Literacy

Summative Evaluation Report

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ABSTRACT

Local to Global (L2G) is a proof-of-concept project that seeks to merge two display systems—an interactive kiosk developed in-house by the Lawrence Hall of Science and the Science On a Sphere (SOS) developed by NOAA—to tell compelling local seismic stories in a global context. This report details findings from the summative evaluation.

Introduction

Local to Global (L2G) is a proof-of-concept project that seeks to merge two display systems—an interactive kiosk developed in-house at the Lawrence Hall of Science, and the Science On a Sphere (SOS) from the National Oceanic and Atmospheric Administration (NOAA)—to tell compelling local seismic stories in a global context. Funded by the National Science Foundation Geoscience Education Program, this project is a partnership between the Lawrence Hall of Science (the Hall) and the Berkeley Seismological Laboratory (BSL) that and aims to: 1) advance the public’s earth system science literacy, and 2) use technology to facilitate geoscience education. The project developed two geoscience “stories” for the integrated system that feature localized seismic events as a springboard for learning about the larger, global picture of seismology. Each story was developed for presentation so that it can be explored without facilitation. This study focuses on evaluating the integrated system as implemented at the Lawrence Hall of Science.

The Integrated System

The integrated kiosk and Science On a Sphere system was set up in the SOS exhibit hall at the Lawrence Hall of Science. This space is located at the center of the main public floor of the science center.



Science On a Sphere at The Lawrence Hall of Science

The L2G project aimed to create a merged system where visitors could explore seismological datasets on SOS and delve deeper via the kiosk to experience the stories through visuals and narration (written and audio). The two geoscience stories created for this project are described briefly below.

Disasters Past & Future

This story discusses three hazards that can make an earthquake a disaster: tsunamis, building collapse, and liquefaction. For each hazard, examples of recent earthquakes are provided to demonstrate why the disasters occurred and what could be done to reduce danger from that hazard in the future. The data sets displayed on the SOS include time lapses of earthquake occurrences, the spread of tsunami waves, maps of tsunami destruction by severity, maps of 8- and 9-magnitude earthquakes, and a time lapse of earthquakes leading up to and following the 2011 earthquake in Japan. At certain points in the story, images or videos are overlaid on top of the data sets displayed on the SOS (e.g., images of building collapse in Haiti and a video of liquefaction in Japan). There are ten kiosk screens for this story (see Appendix A for screen shots).

Seismic Waves

This story focuses on seismic waves and how they contribute to our understanding of earthquakes and Earth structure. Specifically, this story talks about two types of seismic waves (P waves and S waves), how seismic waves travel across and through the earth, and how seismic waves can act like “X rays” to help us see the interior of the Earth. The data sets displayed on the SOS include time lapses of earthquake occurrences, seismic waves traveling over the earth’s surface, and color-coded tectonic plates that indicate their movement and relative age. At certain points in the story, images or videos are overlaid on top of the data sets showing on the SOS (e.g., videos demonstrating the movements of P and S waves, a video modeling how seismic waves move through the interior of the earth). There are five kiosk screens for this story (see Appendix B for screen shots).

Methods & Sample

The Research Group at the Lawrence Hall of Science conducted a summative evaluation of the Local to Global project. The evaluation was guided by two primary questions:

- Can visitors successfully navigate the integrated system?
- What are the geoscience learning gains for visitors participating in the experience?

In addition to these questions we constructed at the beginning of the project, another question emerged during implementation:

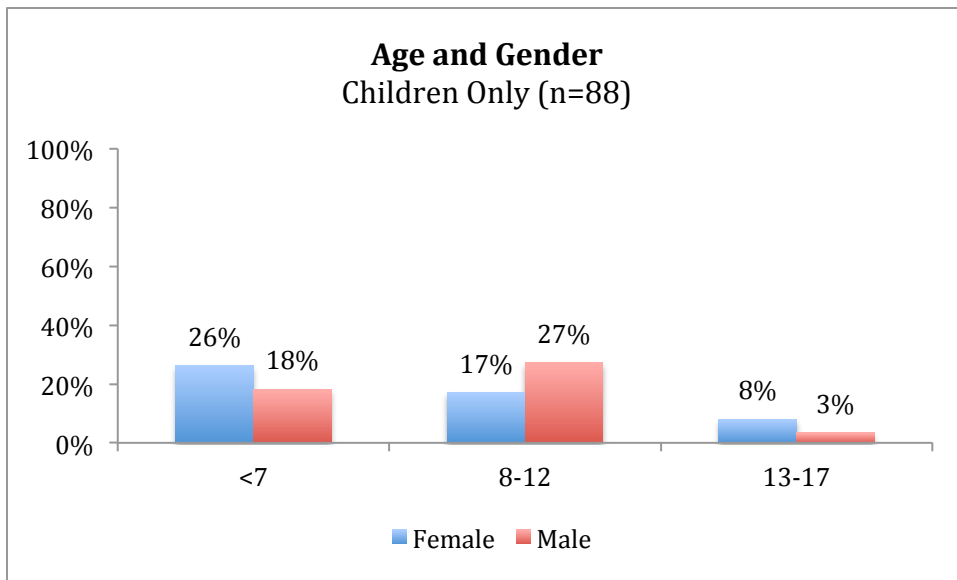
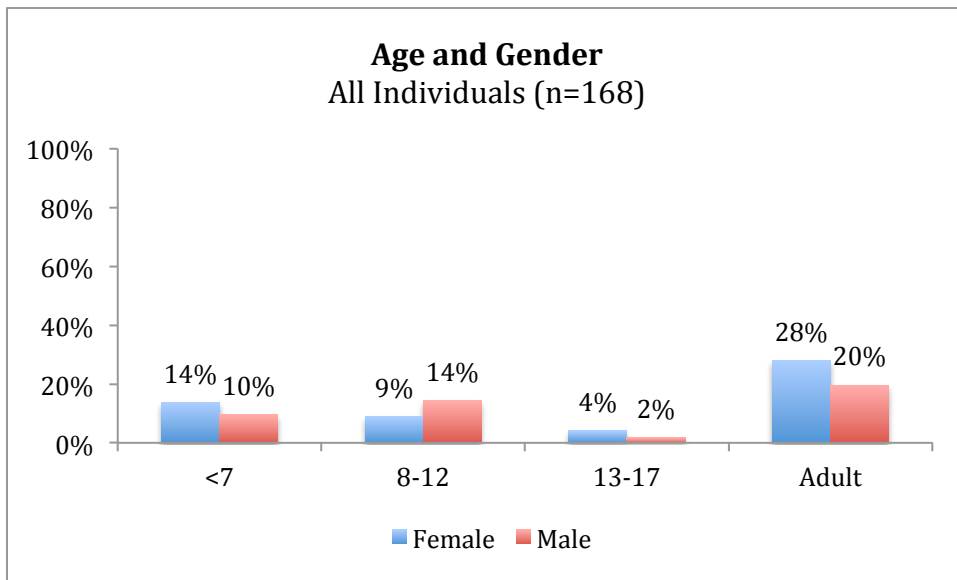
- What are the successes, challenges, and opportunities that might inform future work using the integrated system?

To answer these questions, an observation tool was developed to document the experiences of visitor groups regarding navigation of the integrated system, engagement with the stories viewed, and any issues that emerged. An evaluator observed visitor groups as they engaged with the integrated system, taking running notes. When groups finished, an evaluator invited adults from the group to participate in an interview that asked about using the integrated system, what they learned from the stories, how interesting they felt the stories were, any issues or confusion, and ideas for improving the experience. In order to increase participation in the study, some visitor groups were recruited from the museum floor.

Observations were primarily collected on weekdays during the summer of 2015 (July-August), when attendance is relatively high at the Lawrence Hall of Science. On two occasions when observations were scheduled for a weekend, technical complications with the audio required postponing the observations. A total of 34 interviews were conducted, and 56 observations were collected as noted below:

Story	Observations
Disasters Past & Future	27
Seismic Waves	27
Both Stories	2
Total	56

Visitor groups included in this study were primarily families (89%) and represent 168 individuals. There were also three school/camp groups, two groups for which the group type was not specified, and one Hall staff person on their lunch break. About half of the individuals in observed groups were children (52%), with equal numbers of girls (51%) and boys (49%) who are primarily in the 7 or younger (44%) and 8-12 age groups (44%). There were slightly more female adults (59%) than male adults (41%).



A facilitator was present in the SOS space in 29% of the observations, but only 14% of observations included any interaction between visitors and the facilitator. Facilitation primarily included an introduction to the kiosk and SOS, with additional facilitation beyond an introduction (e.g., more extensive explanation of navigation) occurring in only one of the observations¹. The facilitator present in the observations was primarily staffing another exhibit in the same space, making the Local to Global geoscience stories an unfacilitated experience.

¹ In another observation that was ultimately not included in the study because visitors did not watch the Local to Global stories, a different facilitator took control of the sphere using an iPad and talked about data sets with visitors. In this highly facilitated observation, adult visitors in the group engaged in discussion with the facilitator (asking questions, responding to questions) for 25 minutes.

Summary of Findings

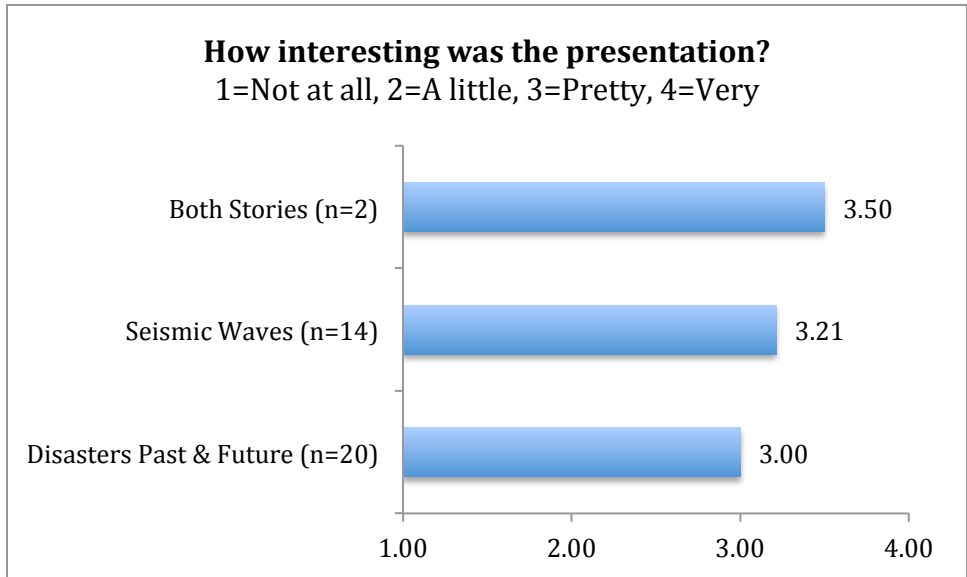
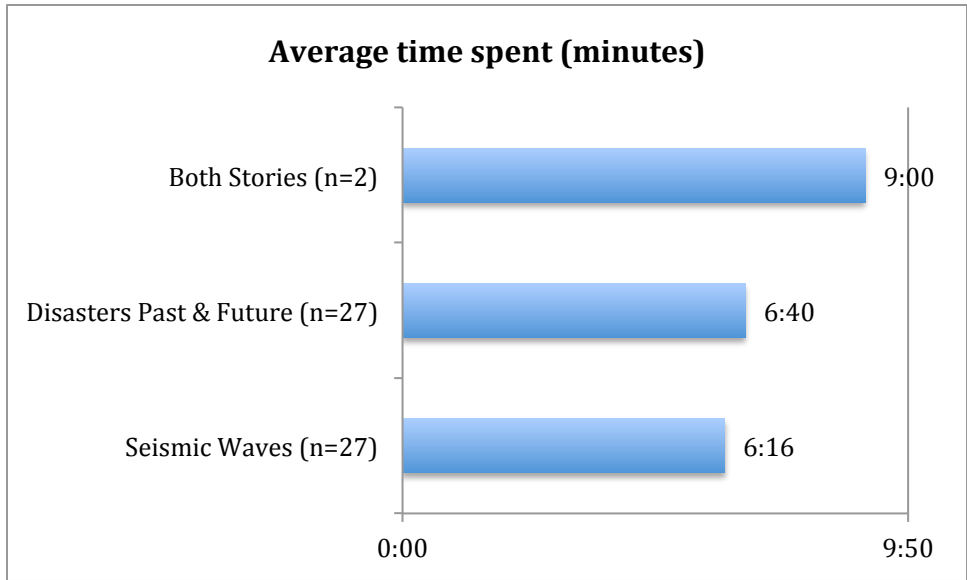
- Visitors spent an average of about six minutes engaging with the Disasters Past & Future and Seismic Waves stories. While visitors were more likely to finish viewing the shorter Seismic Waves story (5 kiosk screens) than the longer Disasters Past & Future story (10 kiosk screens), only about half did so. This suggests that visitors may prefer presentations that are even shorter than Seismic Waves.
- Visitors understood the general content of the two stories. Using three categories for depth of learning developed *post-facto* to code interview responses, the majority of visitors (82%) indicated learning at a Levels 2 and 3 (i.e., noting at least two ideas or examples relevant to the content of the presentation). Visitors moved through the stories primarily in a linear fashion and often did not finish viewing the presentation. This contributed to visitors taking away general ideas rather than the full depth of each story's content.
- Visitors who viewed the shorter Seismic Waves presentation were somewhat more likely to discuss content with members of their group than those who viewed the longer Disasters Past & Future presentation. These content discussions often emerged from visitors pointing out or explaining what they see on the sphere. This study raises questions about the importance of engaging visitors in discussion about data sets on the sphere. For example, what impact could increased discussion have on length of engagement, completion of presentation, and learning?
- Viewing a story in its entirety and engaging in advanced navigation (e.g. using navigation options to search for or investigate information) seem to have a positive relationship with learning (as defined by the number of relevant ideas visitors mention learning about during their interview). While this study cannot explain this relationship, it may suggest that extended engagement with the integrated system has a positive impact on learning. Other explanations may include that visitors with prior interest or knowledge are more likely to view the entire story or investigate information. Future studies should take visitors' prior interest and knowledge into account to explore this.
- The majority of visitors (77%) successfully navigated the integrated system at a basic or advanced level. However, visitors felt that increasing the interactive features (e.g., browsing information on other screens at your own pace, zooming in to find more information) would improve their experience.

Detailed Findings

Visitors enjoy the integrated system and geoscience stories

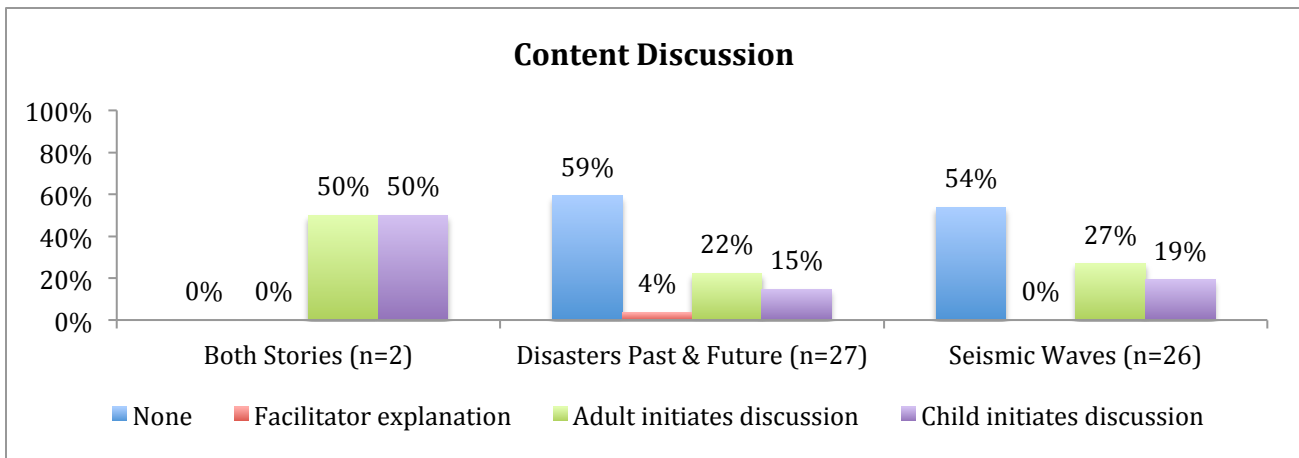
Visitors thought that the integrated system was “very cool”. They enjoyed the high quality visuals shown on the sphere and felt that together the sphere and kiosk “helped each other tell a story about earthquakes”. Visitors enjoyed having control over the sphere, such as being able to rotate the globe. Some visitors noted that the sphere and the kiosk were “synchronized” or had the same information. A couple visitors mentioned liking the audio so they could listen and watch the globe, while another couple of visitors mentioned liking that they could read the text on the kiosk to accompany the audio. See Appendix C for a list of responses to relevant interview questions.

On average, visitors spent six minutes or more engaging with the geoscience stories through the integrated system, and found the presentations interesting.



Visitors understood general content

Visitors discussed content while viewing the stories in 37% of the Disasters Past & Future observations, 46% of the Seismic Waves observations, and both of the observations where visitors viewed both stories. In the observations where content discussion occurred, adults initiated the discussion somewhat more frequently than children. These discussions are most frequently comments, observations, or explanations of what visitors observe in the data sets on the sphere. For example, in observations of Disasters Past & Future, discussions included explaining to another member of the group that the dots on the globe are earthquakes, pointing out the size or location of various earthquakes to members of the group, asking a member of the group what the sphere is showing, or explaining to a member of the group what they know about tsunamis. Discussions observed of Seismic Waves similarly included general discussions of what visitors observe on the sphere, as well as more mentions of content specific in the presentation (e.g., tectonic plates and how seismic waves move across and through the earth).

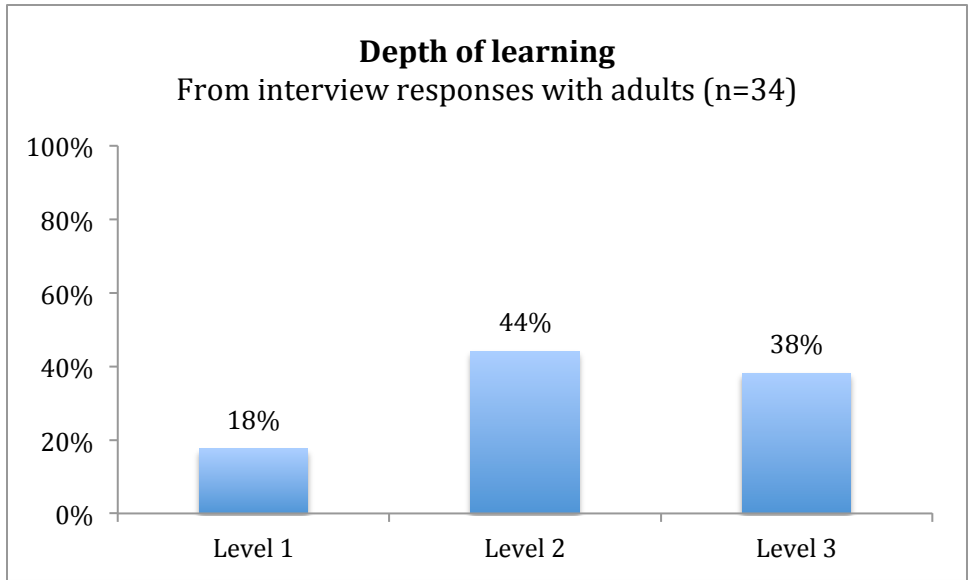


Interviewed visitors (n=34) easily named earthquakes as the topic of both presentations. Visitors often mentioned earthquakes in general, but sometimes also mentioned learning about the number, location, strength and frequency of earthquakes. When describing what the Disasters Past & Future story was about, visitors frequently mentioned the connection between earthquakes and disasters or destruction. Slightly less frequently, visitors mentioned a specific hazard that contributes to disasters, such as tsunamis, infrastructure, and liquefaction. Tsunamis were the most frequently mentioned hazard, and a couple visitors mentioned liquefaction, saying it was something they didn't know about before. This is interesting given that liquefaction is a local risk in the Bay Area. Visitors mentioned learning about the specific earthquake examples mentioned in the story, such as those in Japan, Haiti, and the Indian Ocean. Two comments from visitors about what they learned suggested they might not have fully understood the content. Given the short engagement times observed, this may reflect more on the brief engagement than the clarity of the story. When describing what the Seismic Waves story was about, visitors mentioned seismic waves that spread out as a result of earthquakes. Some visitors mentioned learning about different types of waves, with two visitors specifically mentioning P and S waves. Other specific topics that were mentioned a couple times each were tectonic plates and how seismic waves can map the earth's interior. In their interviews, a few visitors mentioned some particular visuals they enjoyed most, including the earthquake time lapse (Disasters) and seismic waves moving across and through the earth (Seismic Waves). Other visitors said they enjoyed the information or interesting learning opportunity more generally. See Appendix C for a list of responses to relevant interview questions.

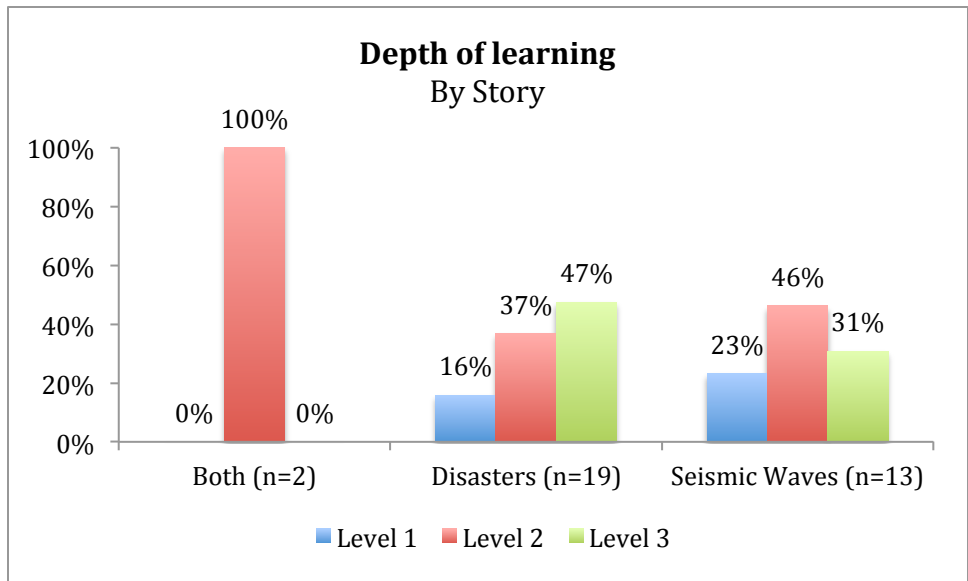
Responses to the interview question about what visitors learned from the presentation were coded into three categories to represent depth of learning. The following criteria were used to code the responses:

- *Level 1* – Generally names the topic of the presentation (e.g., earthquakes).
- *Level 2* – Mentions two ideas relevant to the presentation content (e.g., disasters are caused by earthquakes; earthquakes and tsunamis).
- *Level 3* – Mentions more than two ideas, which may include details, examples, or explanations of how things work (e.g., Earthquakes and tsunamis disasters. The infrastructure of the countries they happen in makes a big difference.) Level 3 represents the most detail visitors provided when discussing what they learned from the stories.

Using these categories for depth of learning, the majority of interviewed visitors (82%) indicated learning at Levels 2 or 3 (i.e., sharing at least two ideas or examples).



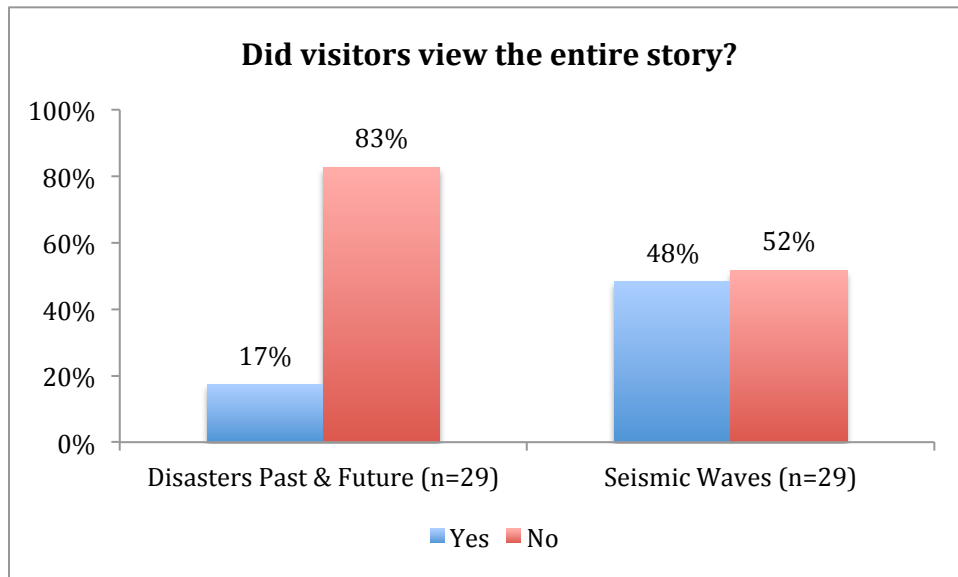
It is important to note that these categories were developed *post-facto* by the evaluator. Due to the fact that these categories rely on visitors naming concepts and examples, the Disasters Past & Future story appears to have more frequent instances of Level 3 learning (shown in the chart below). This may be due to the fact that there were more concepts and examples included in the Disasters Past & Future presentation than the shorter Seismic Waves presentation. As explained further below, most visitors use basic navigation to proceed through the story in a linear fashion and frequently do not finish viewing the entire story. As a result, visitors may not engage with content at the end of the presentation. For example, visitors who viewed Disasters Past & Future frequently mentioned earthquakes, disasters, or even tsunamis, but less frequently mentioned other hazards such as building collapse or liquefaction specifically, which were addressed later in the story. For Seismic Waves, visitors frequently mentioned earthquakes and seismic waves, but less frequently mentioned tectonic plates or how seismic waves help map the interior of the earth, which were addressed later in the story.



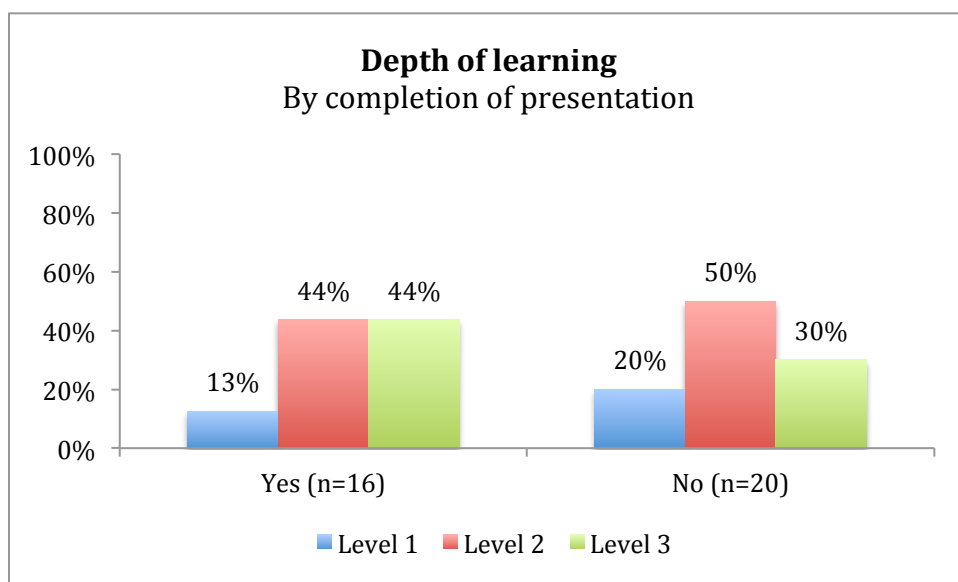
Further work is needed to better understand differences between the stories, especially which elements of the stories have a positive impact on visitor learning. Moreover, further discussion of preferred ways to define and measure learning outcomes for visitors using the integrated system will allow more nuanced data collection and analyses in future studies.

Visitors prefer short, accessible stories

Visitors were much more likely to view the entire Seismic Waves story than the entire Disasters Past & Future story.



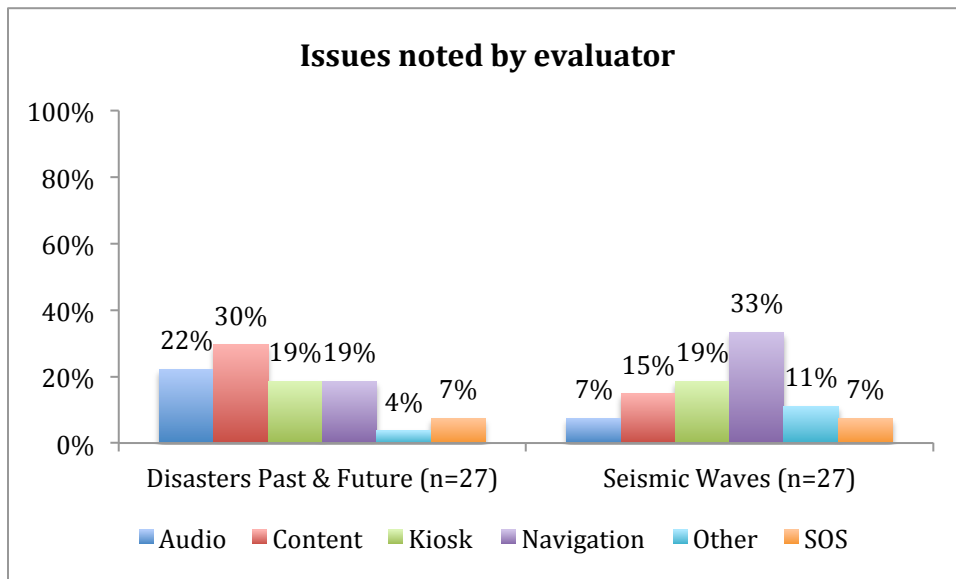
This difference may be related to the length of the presentations, since the Seismic Waves story has half as many slides on the kiosk (five) as the Disasters Past & Future story (ten). The length of the stories may also have impacted visitors' ratings of their interest in the two stories. Although visitors rated their interest in the presentations similarly, average ratings for Disasters Past & Future (3.00 out of 4) were slightly lower than those for Seismic Waves (3.21 out of 4). A presentation that is too long could lose visitors' interest. This study suggests that viewing the entire presentation supports deeper learning. Those who completed viewing a story shared more evidence of Level 3 learning in their interviews (44%) compared to those who did not view the entire story (30%).



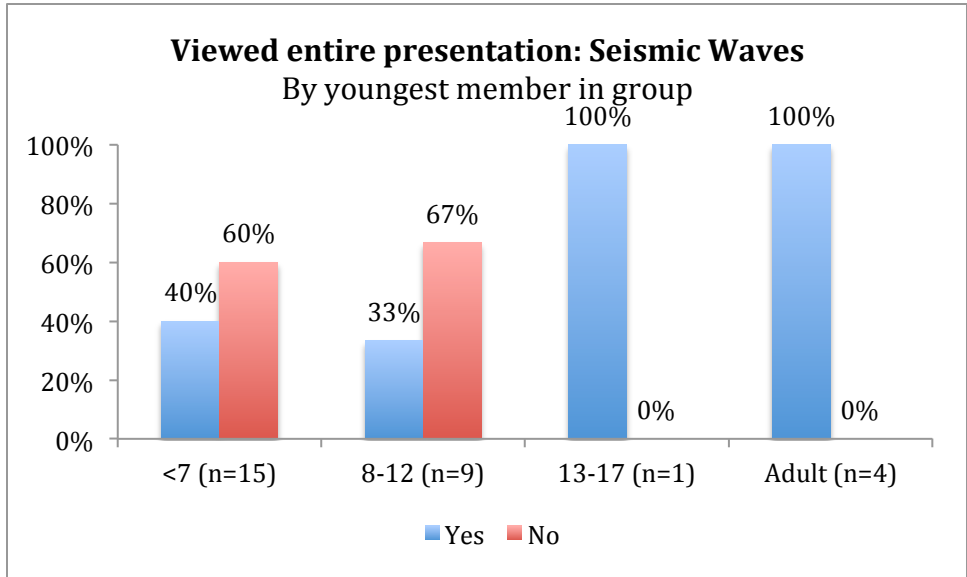
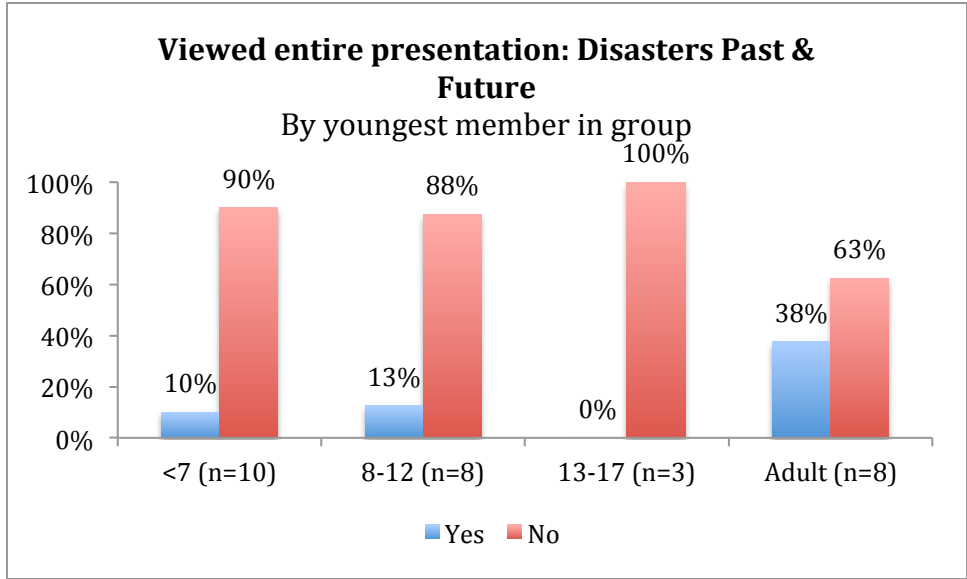
It is important to note that although visitors more frequently completed the entire Seismic Waves story, more than half of the visitor groups did not view this entire presentation either. This may suggest that the number of slides, length of narration, or content in Seismic Waves may still be too complex to fully engage visitors as intended. Most directly to this point, interviewed visitors suggested that shortening or

simplifying the stories and their content (e.g., having shorter presentations, breaking presentations into smaller sections, not putting information on the globe and screen at the same time) would improve the stories.

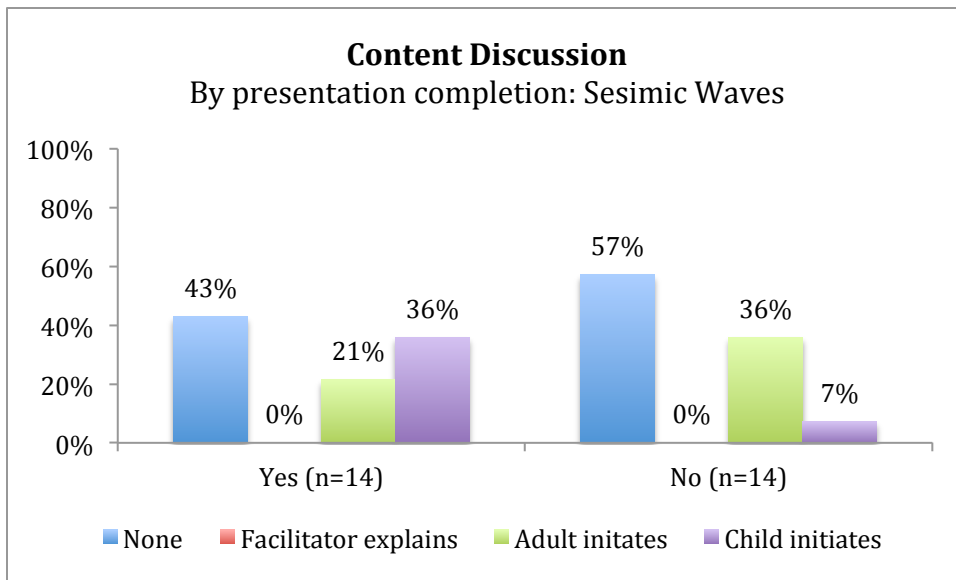
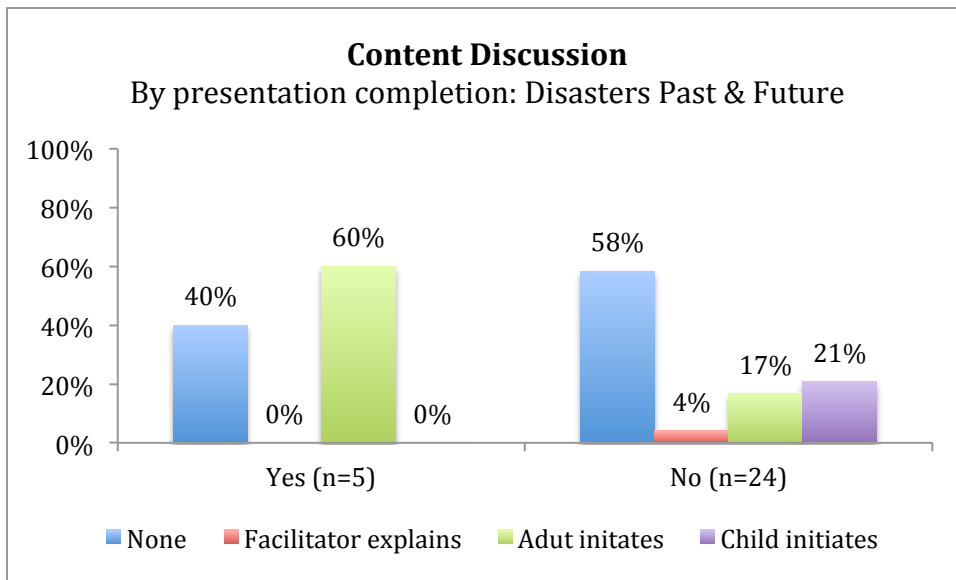
During their interviews (n=34), some visitors explained that they felt overwhelmed with the amount of information presented at once on the globe, kiosk, and audio. Because there was information presented in multiple places at once, they weren't sure where to focus their attention. Further to this effect, images or videos placed on top of data sets on the sphere were overwhelming to some visitors; they felt like the overlays covered up information they wanted to see in the data set, and it added an extra layer of information to the already complex display. Another comment that suggests visitors would prefer modifications that reduce the density of the stories was having an option to turn off the audio. The types of issues or confusion noted by the evaluator echoed these sentiments. Based on observations and interviews, the evaluator noted higher percentages of issues or confusion related to content and audio for the longer, more detailed Disasters Past & Future story than for Seismic Waves.



Ensuring that content is accessible for a range of ages, especially younger children, came up as well in the interviews and is also related to the idea of shortening and clarifying the focus of stories. In the charts below, visitor groups are organized by the youngest member present in the group. Groups with young children were less likely to finish viewing either story than groups with all adults. This suggests that modifications to the stories might help better engage families with young children.

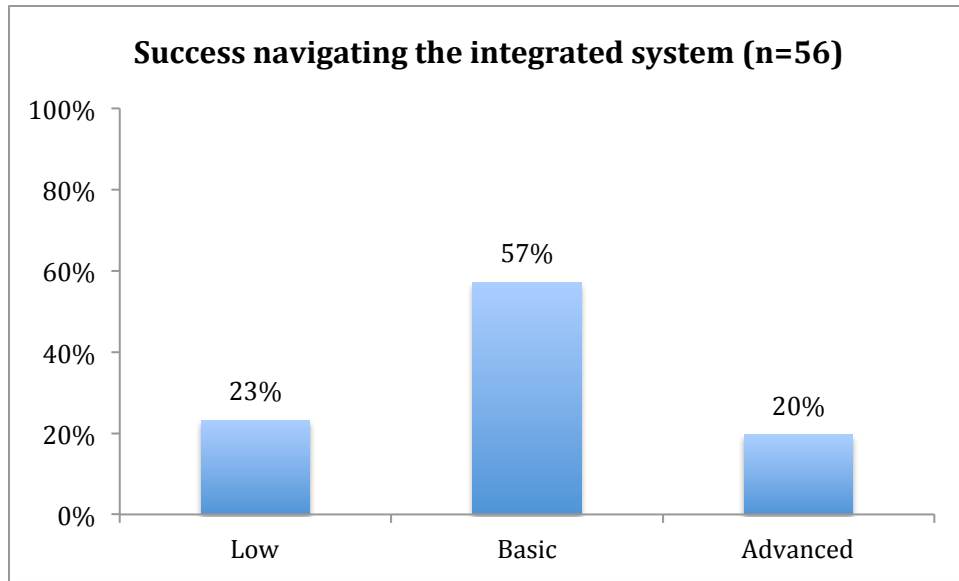


Although the sample size is small, children initiated content discussion more frequently while engaging with the Seismic Waves story than with the Disasters Past & Future story. This could indicate that a shorter, simpler story better engages children. By designing stories with children as a target audience, they may be more successful for all general public audiences as well.

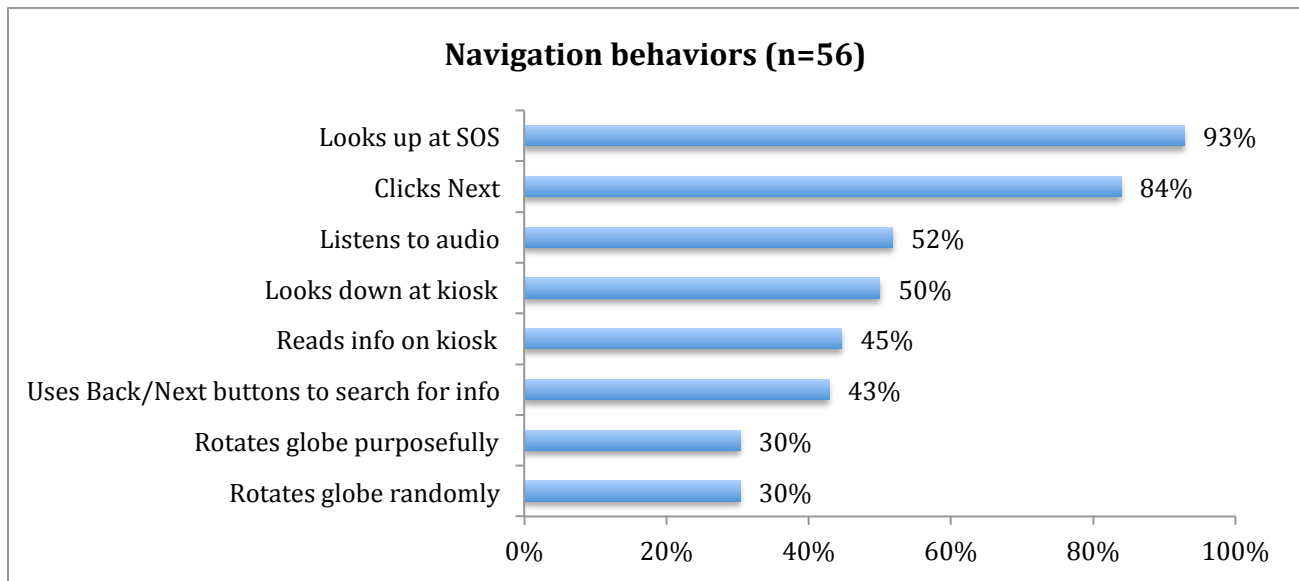


Basic navigation is successful

More than three quarters of visitors (77%) successfully navigated the integrated system. At a basic level, visitors used navigation options to progress forward in the show (e.g., click through the slides/datasets, follow prompts, and listen to audio or look between the kiosk and the SOS). At an advanced level, visitors used navigation options (e.g., rotating the globe or toggling between slides) to search for or investigate information. About a quarter of visitors (23%) struggled to navigate between the kiosk, audio, and/or SOS at a basic level to proceed through the story or engage with the content and visuals. In some cases these visitors didn't engage with aspects of the integrated system (e.g., listening to audio or reading text on the kiosk), they rotated the globe randomly without engaging more intentionally, or they did not navigate past the first slide. None of the visitors who had low success with navigation finished viewing the stories.

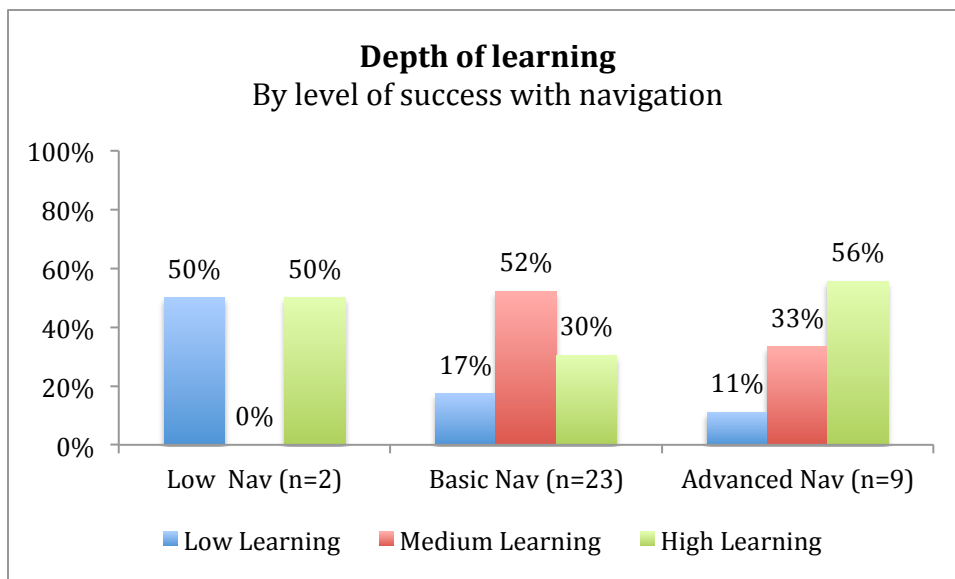
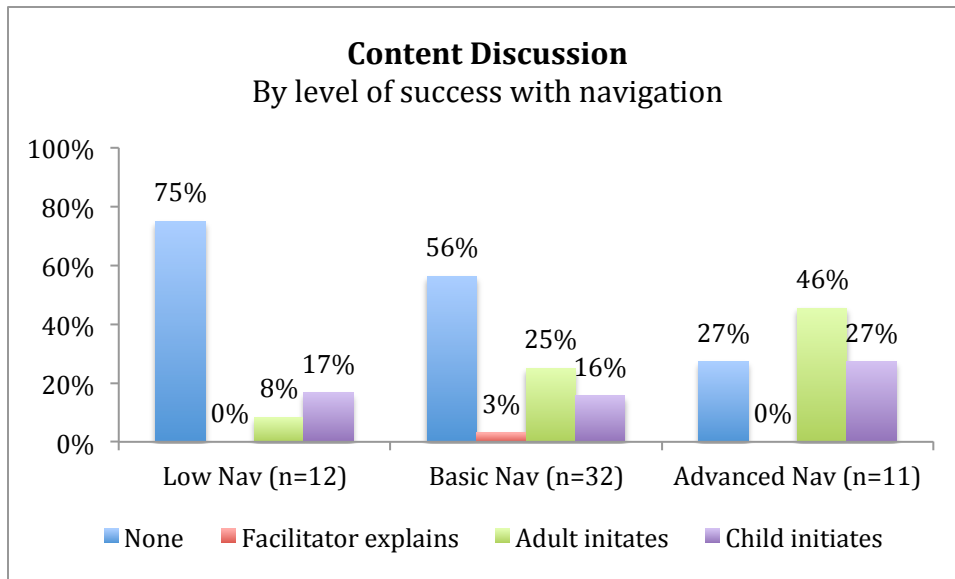


Below is a summary of the navigation behaviors observed. Almost all visitor groups looked up at the SOS (93%) and clicked the “Next” button to proceed through the story (84%). Only about half of groups seemed to listen to the audio (52%) or look down at the kiosk (50%), with slightly fewer reading text on the kiosk (45%) or using the “Back” or “Next” buttons to search for information in the story (43%). Less than a third of groups used the rotation function purposefully to view different parts of the globe (30%), and less than a third rotated the globe randomly without out intentionally exploring the data sets (30%).



While it wasn’t possible to distinguish between children’s and adult’s success with navigating the integrated system through this study, it is worth studying this in the future to better understand both the usability of the integrated system for children of different ages as well as the accessibility of the content for different ages (as discussed in the previous section). This study suggests that successful navigation and content discussion may be related. As shown below, visitors initiated content discussion in almost three quarters (73%) of observations when they were engaged in advanced navigation, compared to just 41% for

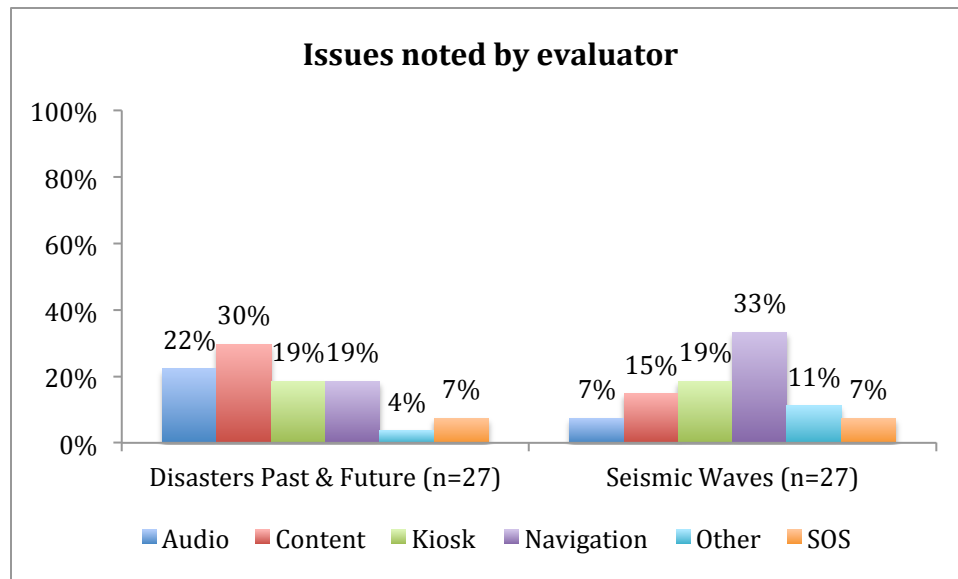
basic navigation. Further to this point, those who engaged in advanced navigation provided responses in their interviews that suggested higher levels of learning—56% Level 3 learning for those who did advanced navigation compared to only 30% Level 3 learning for those who did basic navigation. While the relationship between these is unclear, and must also consider visitors’ prior interests, it will be useful to continue studying this in the future to determine how navigation, content discussion, and learning can foster a positive and impactful learning experience for visitors.



Visitors want a more interactive interface

While some visitors noted that they enjoyed being able to rotate the globe via the kiosk, one of the main suggestions for improving the stories was having “more to do” and making the stories more interactive. Visitors had a few different ideas about what this might look like, including having more presentation options, being able to browse different content at your own pace/preference on the different screens available, turning the audio on/off, selecting presentations in different languages, choosing what to explore in greater detail, or zooming into specific areas on the globe.

Issues and confusion visitors had with the Seismic Waves story compared to the Disasters Past & Future story suggests that shorter/simpler stories may encourage visitors to try out navigation or interactive features that are available. Visitors engaging with the Seismic Waves story experienced more challenges with navigation than those engaging with the Disasters Past & Future. Since the navigational features are the same between the two stories (e.g., next, back, rotating globe), visitors engaging with Seismic Waves were more likely to try the rotation feature. Perhaps they would also explore additional interactive features if they were available for brief stories.



Interestingly, a few visitors did not recognize the level of interaction the current integrated system did provide. That is, they thought that the kiosk was used to select a view-only presentation (e.g., a movie) or that the kiosk was not for visitors to use. This emphasizes the importance of including visual cues for visitors in the space and on the kiosk to encourage them to interact with the various interactive features of the integrated system.

Conclusions & Recommendations

Shorten and simplify stories to help visitors focus on and discuss data sets

Visitors engaged with the stories for an average of slightly over 6 minutes. Within this time, the majority of visitors did not view the stories in their entirety. Consider shortening stories or creating shorter independent blocks of stories that visitors can engage with in just a few minutes. Below are some strategies that may help shorten and clarify stories.

- Limit the amount of new information introduced at any one time. Some visitors found the multiple layers of information introduced via the integrated system to be overwhelming. Consider modifications that might help ease this. For example, inserting more pauses and prompts that indicate where visitors should focus their attention or introducing overlays after there has been sufficient time to study the data set first (or temporarily replacing the background with a solid color while the overlay plays). Introducing more visitor controls could also help with this. For example, visitors could select when they are ready for the next layer of information about that part of the story.
- Additional pauses and prompts introduced into stories could also support additional discussion of geoscience data sets. Because most of the observed content discussions were observation, explanation, and questions about the data sets on the sphere it is important to foster engagement with that information. Evidence from the evaluation of a previous SOS project at the Hall called

*Linking Evidence to Explanation in Global Science*² found that pausing autorun presentations on the SOS to give visitors a chance to express their ideas to each other increases scientific thought processes.

Explore strategies for making the integrated system more interactive

- One of the main suggestions visitors had for improving the stories was making them more interactive. Consider ways to allow independent browsing of geoscience information on the non-kiosk screens. Furthermore, consider ways to allow visitors to explore story content in more depth (e.g., when to view videos and images, zooming in to particular locations for more detail). To support visitors' use of these interactive features, ensure that there is enough signage or visual cues to explain navigation and functionality.

What does learning look like for visitors using the integrated system?

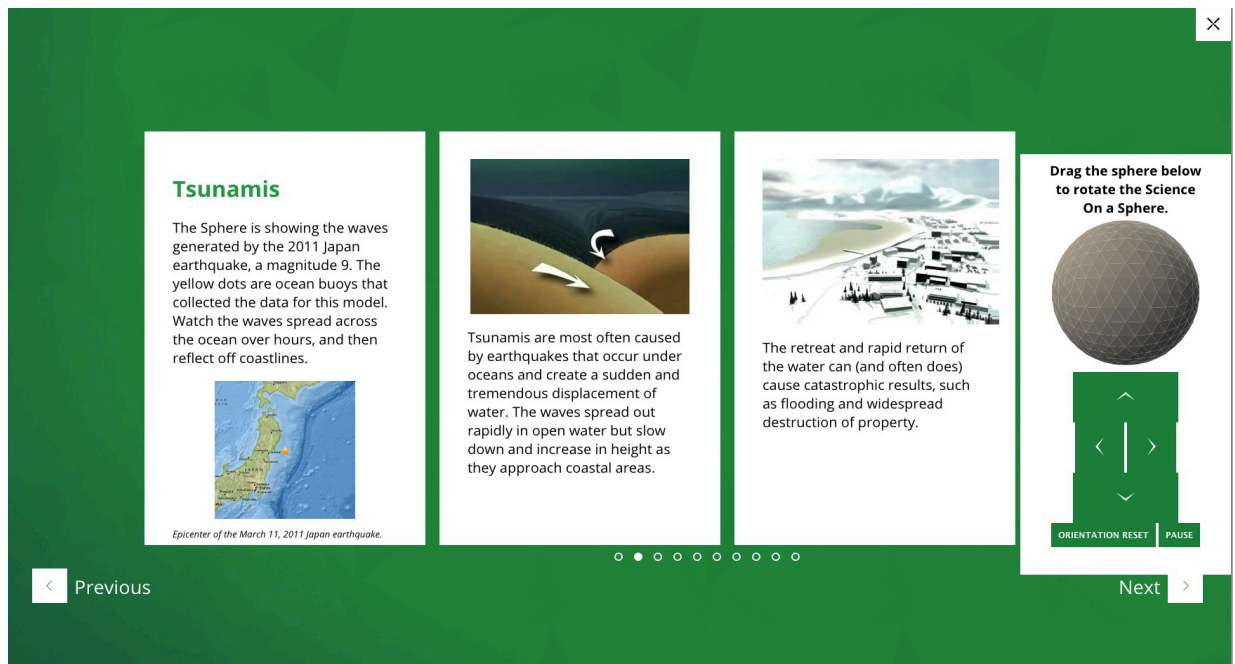
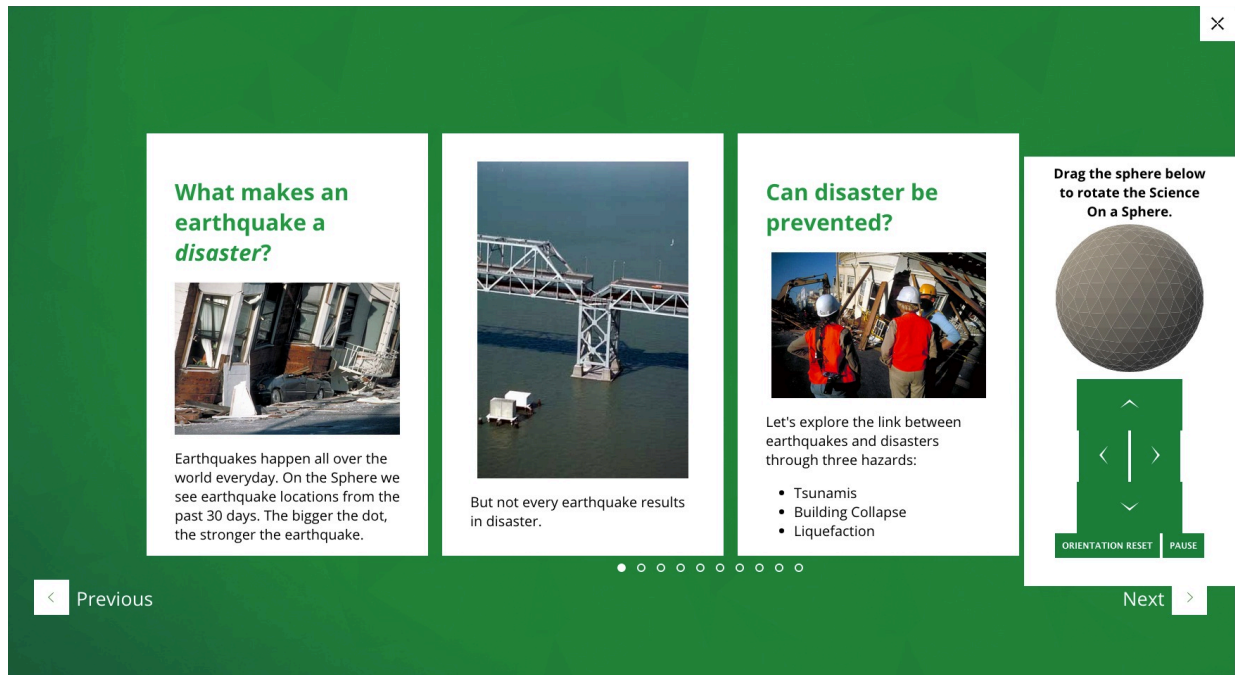
- In this study, the criteria for “learning” were developed *post-facto* and focused on the number of relevant concepts mentioned by visitors. Further clarify what visitor learning might look like when using the integrated system (e.g., inquiry behaviors, content knowledge) and design future studies to measure these desired learning outcomes more specifically. In future studies, also consider visitor prior interest or knowledge in the topic.

Continue making improvements to the existing set-up

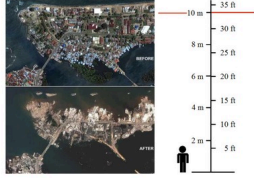
- Continue refining the navigation and audio components of the integrated system to improve usability. Formative recommendations for the Lawrence Hall of Science are detailed in a separate report.

² Werner-Avidon, M., Castillo, C., Newton, L., Robles, D., Randol, S. (2011). *Linking Evidence to Explanation in Global Science: Evaluation Report*. Prepared for the Public Science Center at the Lawrence Hall of Science.

Appendix A: Disasters Past & Future Kiosk Screen Shots



Compare the 2011 Japan tsunami with the 2004 Indian Ocean tsunami now showing. Observe how the waves travel across and reflect off the coasts surrounding the more enclosed Indian Ocean.

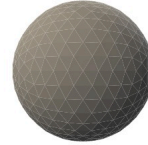


The 9.3 Indian Ocean quake was one of the worst natural disasters in recorded history, killing more than 200,000 people. Waves reached over 10 m and hit many nearby coastlines.



Although the highest waves from the Japan quake were 4 times taller, there were 1/10 of the casualties from the Indian Ocean quake. Despite the devastation in both cases, the openness of the Pacific Ocean versus the Indian Ocean and Japan's prior experience with tsunamis and preparation help prevent a greater disaster.

Drag the sphere below to rotate the Science On a Sphere.



ORIENTATION RESET PAUSE

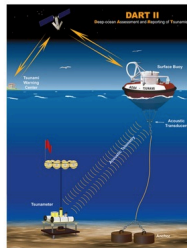
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Can we reduce the danger?

Tsunamis cannot be prevented, but with careful planning we can reduce the danger to humans. Each of the 1200 dots on the Sphere represents a tsunami event from the last 4000 years, color-coded by degree of devastation. Scientists use records such as this to assess past tsunami patterns and predict future danger.

Today, there is a worldwide effort to identify high-risk areas for tsunamis, and set up advance warning systems and evacuation routes.



Sensors on the ocean floor measure tsunami magnitudes and send that data to DART buoys above. They then relay the data to warning centers, where scientists track tsunamis and can save lives.

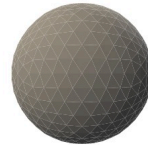


Here in the Bay Area, we cannot generate a tsunami, but we may get hit by one. Having some distance from a tsunami's origin will give us some time to react before waves reach us.

Be prepared. Possible tsunami warning signs include:

- A strong, 20-second or longer earthquake near the coast
- A noticeable rapid rise or fall in coastal waters

Drag the sphere below to rotate the Science On a Sphere.



ORIENTATION RESET PAUSE

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Building Collapse



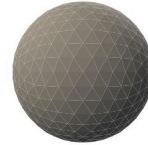
Large earthquakes have occurred throughout history. The Sphere shows magnitude 8 and 9 earthquakes from 1900-2014. We also see the damage to buildings in one of the most devastating—the 7.0 2010 Haiti earthquake.

Before the earthquake, building codes in Haiti were not enforced and cheap concrete without enough cement was routinely used. Builders also often used thin, inconsistent rebar reinforcements and failed to use enough cross-structures within rebar reinforcements. Builders also failed to pack down concrete used in building walls.



All of this resulted in weak buildings, leading directly to a greater loss of life due building collapse.

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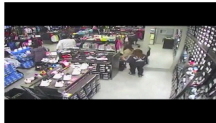
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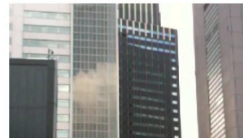
Here we see the three weeks leading up to and the two weeks after the 2011 Japan earthquake. Watch for the giant dot to appear on March 11.



This earthquake was 1000 times stronger than the Haiti earthquake. Yet despite several large foreshocks and aftershocks, few Japanese buildings collapsed due to the earthquake shaking.



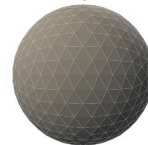
Office workers walking home after the earthquake. In the background you can see very little damage to office buildings.



Japan's swaying buildings during an earthquake.

In sharp contrast to Haiti, Japan enforces some of the strictest building codes in the world. Its buildings are designed to get through quakes with minimal structural damage. Not surprisingly, California—the birthplace of seismic regulations and the Structural Engineers Association of California (SEAOC)—has been investigating and strengthening seismic codes since the great earthquake of 1906. Like Japan, California has some of the strictest building codes in the world. So building codes matter, and enforcement can save lives.

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Liquefaction

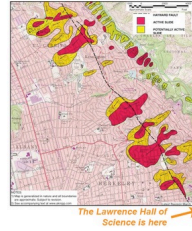
Liquefaction is the process by which water-soaked land temporarily loses strength, acts like a fluid, and water wells up from the ground. This is a concern at many earthquake sites.



Liquefied sand that flowed over onto fields during the 1989 Loma Prieta earthquake.

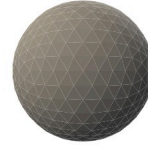
A combination of factors leads to liquefaction like the video example on the Sphere:

- Loose sediment: soil such as sand and soft clays.
- Water saturation: water sources underground but close to the surface; being close to bodies of water; excess rain
- Strong shaking: like a quake!



The video shows water welling up due to liquefaction during the Japan earthquake. This map of Berkeley and El Cerrito highlights landslide risk areas. They are also areas at risk for liquefaction.

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Dangers from liquefaction



Strong earthquakes in areas at risk for liquefaction can lead to disaster. The 6.9 Loma Prieta earthquake in 1989 caused liquefaction underneath this freeway structure in Oakland, CA, resulting in its collapse. The structure was built on filled land and bay clay—a land type ripe for liquefaction. *What other damage can liquefaction do?*

It can damage infrastructure



In 2011, a 6.3 struck Christchurch, New Zealand. Liquefaction formed "sand volcanoes" and sinkholes, destroying roads and slowing rescue operations. Cars literally sank into roads.

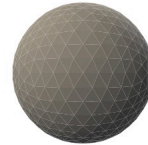
It can damage buildings



During the 7.6 earthquake in Niigata, Japan in 1964, the foundations of these apartment complexes sank in the suddenly liquefied land, toppling the buildings above.

Bridges, buildings, and roads can fall when liquefaction strikes.

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Can we reduce the danger of liquefaction?

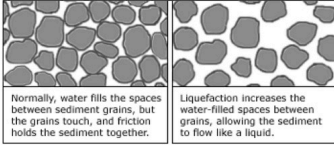
The Sphere shows a record of earthquakes and volcanic eruptions from 1960 to 2010. In that 50-year period, there were over 70,000 earthquakes over magnitude 5—many of which probably caused liquefaction. We have only recently been made aware of the dangers of liquefaction and are developing techniques to lower the risk.

Location Consideration

One way to reduce the dangers of liquefaction is to avoid building on soil that is susceptible to liquefaction.

Structural Modification

Digging deeper foundations with larger, stronger piles also allows engineers to stabilize the buildings atop those regions.

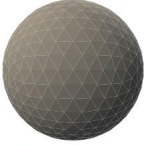



Source: NASA Earth Observatory

Soil Modification

Engineers are beginning to consider ways to change the properties of soil around existing structures. By filling the spaces between the grains of soil or compacting the grains we can stabilize the structures built above.

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What does the future hold?

Here we see the Earth at Night and fault lines, where nightlights give a good idea how the world population is spread out. We overlay that with a risk map, with white and green representing low risk for a major earthquake, and pink and red representing high risk.

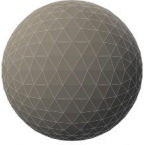
Will the next quake be a disaster? Will disaster strike here?


Be prepared. Make a plan.

<http://72hours.org/>

Building Collapse	Tsunami	Liquefaction
		
<p>Locations at risk:</p> <ul style="list-style-type: none"> • Northern India • Turkey • China <p>What can be done:</p> <ul style="list-style-type: none"> • Enforce building codes • California has the world's strictest codes 	<p>Locations at risk:</p> <ul style="list-style-type: none"> • Puerto Rico • The Pacific Northwest • Chile <p>What can be done:</p> <ul style="list-style-type: none"> • Setup early warning systems • Develop evacuation plans and routes 	<p>Locations at risk:</p> <ul style="list-style-type: none"> • Mexico City • SF Bay Area • Japan <p>What can be done:</p> <ul style="list-style-type: none"> • Survey building sites for risk factors • Compact loose soil before building

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Appendix B: Seismic Waves Kiosk Screen Shots


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Seismic Waves

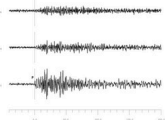
Earthquakes happen around the world every hour of every day. You can see on the Sphere the last 30 days of earthquakes. Huge amounts of energy are released and create **seismic waves** that spread throughout Earth during earthquakes, much like the ripples from a stone tossed into a pond.



Seismic waves help create maps of Earth's interior


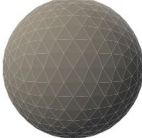


Scientists can use seismic waves to take an "X-ray" of the planet. When you get an X-ray of your body, differences in material like bone and tissue create an X-ray image.



Seismic waves can help us "see" the structure of Earth's interior in much the same way.

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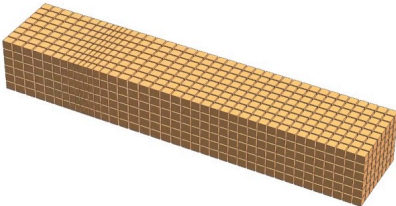
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Seismic Wave Types

There are several different types of seismic waves. We will focus on two of them—P-waves and S-Waves.



P-waves

P-waves, or pressure waves, travel the fastest and tend not to cause as much damage as other seismic waves. Notice the wave moves along the same direction as motion, bunching up and moving like a packet of pressure. Compare the P-Wave motion to the S-Wave motion next.



P-wave motion. Source: Wolfram-Alpha.

Drag the sphere below to rotate the Science On a Sphere.



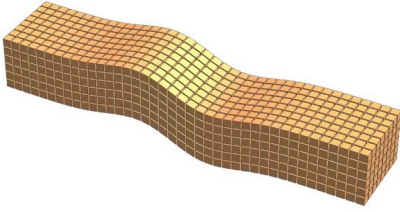
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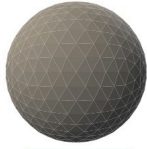
S-waves

S-waves, or shear waves, are like ripples in a pond and can cause severe damage to structures. Notice the wave moves up and down as it moves forward. This relates to the rolling motion often associated with earthquakes. S-waves move slower than P-waves, and will lag behind when an earthquake strikes. Compare the S-wave motion to the previous P-wave motion.



S-wave motion. Source: Wolfram-Alpha.

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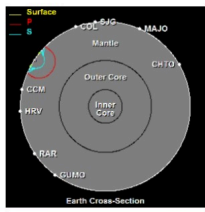
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Seismic waves in action

On the Sphere we see seismic waves from the 1994 Northridge 6.4 Earthquake, near Los Angeles. Like the delay in hearing thunder after lightning, seismic waves take time to travel from the earthquake source. These can be felt by people for hundreds of miles, but the seismic waves actually travel around—and through Earth.

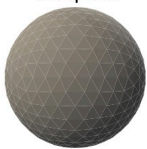


Earth Cross-Section

Seismic waves are detected by stations around the world, indicated by the all-capital letters. Watch the waves move on the surface—how long until they reach New York? Or the opposite side of the world?

Notice the red P-waves travel fastest and can move through Earth's center. The blue S-waves travel slower and do not pass through the interior. The combined effects of P and S waves result in the yellow surface waves. When a seismic wave reaches structures inside Earth (like the border between mantle and core), some of the wave **reflects** off that border and some it bends (or **refracts**). We can measure this reflection and refraction to create pictures of the interior of Earth—just like an X-ray.

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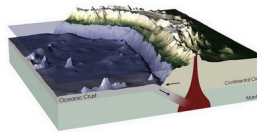
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Seismic Waves as X-rays

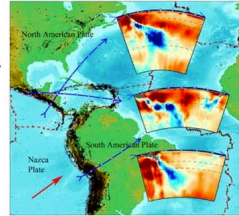
With each earthquake, we see lots of seismic waves. By noting where they bend and reflect, we get a very good idea of what Earth looks like inside, even seeing the core.

On the Sphere we see the ocean floor surface color-coded by age. New land is red and orange; old land is blue and purple. Pieces of Earth's crust—called tectonic plates—are slowly but constantly moving. As they move, old land is recycled and new land is formed.



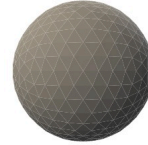
Sometimes one plate moves under another. We call this **subduction**. Often it is a plate covered mostly in ocean (oceanic crust) that slides under a plate holding the continents (continental crust).

These panels of red and blue are "slices" into Earth, like pieces of toast that slide vertically into a toaster. Blue indicates older, denser oceanic crust deep in Earth, long after they have been subducted. Warmer, lighter continental crust shows up as red. The slices are taken from the blue dashed lines on the map.



Thus, seismic waves allow us to study Earth's interior, helping us track plate movement and inner structure.

Drag the sphere below to rotate the Science On a Sphere.



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Appendix C: Responses to Select Interview Questions

How do you think the kiosk screen and the globe are related? (n=34)

Work together to present information

1. I liked them together
2. Very cool! The screen provides information and so does the earth. Lots to see
3. They're synchronized together
4. I thought they're great together
5. Kiosk is like a written version of what's on the globe
6. Display the same information just in different ways, it's cool
7. The kiosk relates to what's on the sphere
8. I really liked how they worked together
9. Kiosk provides the info and the globe usually presents it
10. Show the same info, displays the same cut outs, audio and the words are the same
11. Display the same information
12. They help each other tell a story about earthquakes
13. Hard to hear but the kiosk and the globe worked well together
14. Audio was echoey [sic] and loud, but the screen and globe were great together

Kiosk controls the globe

1. The kiosk controlled the earth
2. The kiosk controls the globe, I guess
3. The kiosk is used to change what's on the sphere
4. The kiosk controls the sphere and has all the information
5. The kiosk controls the globe's images as well as rotating it if you want the audio is also the same as what's on the screen
6. Touch screen, see projector on globe, helps it move, picks subject
7. The kiosk controls the globe
8. The kiosk controls what you see on the globe
9. Frustrating that the kiosk controlled all the other screens as well as the globe
10. Not as interactive as I wish it could have been. You can rotate it but that's it
11. I can control it
12. I thought you just selected the story and sat down

Positive comment

1. I think the globe is very cool
2. Worked great I thought
3. I liked it. Nice so everyone can watch
4. I like the globe and touch screen

Content/Information

1. Very clear and easy to understand
2. I liked the screen and all the information
3. I like it, a lot of information for little kids like mine

What did you like most about using the kiosk and globe together? (n=34)

Visuals on the globe

1. Interesting. Globe had a lot of info and the screen too
2. I don't know, the earth projections are cool I guess
3. The projections of earth and all the info is very cool
4. Love all the live displays of earthquakes occurring on the sphere helps a lot
5. The sphere is really cool
6. The visuals on the globe are very good
7. I like watching the globe to learn
8. Visual of the sphere
9. The live display of earthquakes (time lapse)
10. I like the globe and being able to look at everything on it
11. How visual the earth is for learning
12. The big earth is very interesting and engaging, helps visualize
13. All the visuals on the sphere are very good
14. I liked the globe because it really helped the imagination of it. The earth could be flat otherwise and that's wrong.

Learning/Content

1. I know my grandkids weren't interested but I like that this exhibit is kind of for adults something for us to learn that's still interactive
2. It's a different way of learning that I hadn't really encountered before
3. Thought it was interesting
4. It's fun and very useful
5. How earthquakes are formed
6. All the stuff about the waves
7. I like all the information
8. I liked the diagrams and information
9. Tectonic plate slide was very interesting
10. I thought the seismic wave diagrams were every cool and visually interesting
11. Lots to look at
12. I liked the display of the waves moving across and through earth
13. P wave and S waves were really interesting

Rotating the globe

1. The globe and spinning it is cool
2. I like that you can control it.
3. I liked rotating the globe and being able to watch while the voice explained
4. Rotating the globe
5. Rotating it
6. Rotating it is cool
7. Rotating the globe was very cool
8. Rotating the sphere was very cool
9. Spinning the earth
10. Fun to rotate it

Multiple information sources

1. I liked the audio and the sphere together so I could watch while she talked
2. Helps to have the written paragraphs and the audio
3. I liked being able to watch while the voice explained
4. Liked how the words were written so that if the audio was hard to hear I could still listen

Other

1. I love that it's interactive, just wish it was more obvious that I need to stand at screen rather than sit.

In your own words, what was/were the presentation(s) about? What did you learn about that topic from the presentation(s)? (n=34)

Both presentations viewed

Level 2 Learning

1. Learned where earthquakes occur and how often
2. P wave and S wave and earthquake formation

Disasters Past & Future

Level 1 Learning

1. Earthquakes
2. The stuff about tsunamis was interesting but after that I didn't care as much
3. As an environmental science major I knew a lot of this already but was looking for some future guidance for personal growth. Haven't heard of liquefaction though, so need to learn more

Level 2 Learning

1. Disasters caused by earthquakes
2. Earthquake damage
3. Earthquakes, especially the Japan one
4. Earthquakes—how they form, how strong they can be
5. Earthquakes and tsunamis
6. Natural forces, different storms in different areas, damage caused, why happened, cause tsunamis
7. About earthquakes how they differ and effect the surface differently

Level 3 Learning

1. Ways earthquakes can cause problems and how infrastructure of the country makes a big difference
2. Different ways earthquakes can cause disaster, special reference to Japan, Haiti and India.
3. Earthquakes and how they vary in destruction, gave good examples between Japan and Haiti
4. Disasters caused by earthquakes and tsunamis is as far as I got through
5. Disasters caused by earthquakes and how where they happens can make a big difference
6. Earthquakes and tsunamis disasters. The infrastructure of the countries they happen in make a big difference
7. How destructive the Indian tsunami was in comparison to the japan one
8. About different ways earthquakes can cause destruction. Didn't know about liquefaction or whatever its called
9. The japan earthquake and the damage it caused versus India

Seismic Waves

Level 1 Learning

1. Like to know more about magnitudes
2. Earthquakes
3. They were about earthquakes

Level 2 Learning

1. Different kinds of earthquake waves
2. Seismic activity and how it travels
3. Earthquakes and different kinds of waves
4. Earthquakes. They happen constantly, very scary (laughs)
5. Seismic activity and waves
6. P waves and S waves, tectonic plates. I don't know I wasn't really paying attention.

Level 3 Learning

1. Earthquakes and more specifically different seismic waves and movements. How you can learn about the core of the earth via refraction of these waves travelling, I didn't know that.
2. Earthquakes, tectonic plates, different kinds of seismic waves
3. Different kinds of waves and how much destruction they caused. How many quakes and where they occur
4. Earthquakes, we can know more about the interior of the earth by waves moving through it