Living Liquid
Summative Evaluations

Inverness Research

Living Liquid
Executive Summary

Inverness Research
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Introduction

Inverness Research is the external evaluator for the Exploratorium's Living Liquid Project. This project, funded through the Advancing Informal STEM Learning (AISL) program at the National Science Foundation (NSF), aimed to create visualizations of three large ocean ecology data sets in three separate interactive displays that would facilitate visitor investigations the data. Project leaders created partnerships between museum exhibit developers and learning researchers, ocean scientists, data visualization artists, and computer scientists who worked together to create these three interactive visualizations for a large table platform: one on plankton populations, one on mapping migrations, and one on metagenomics, as well as a research study to identify guidelines for supporting inquiry, and training opportunities for computer science graduates. The goals of the project were to:

- "Advance public understanding of ocean ecosystems and large data inquiry skills through visualization
- Advance STEM professionals' knowledge of engaging the public in inquiry with visualization through an educational research study and
- Increase the capacity of STEM professionals to develop visualizations through collaborative development."

Inverness Research's role on this project has been summative, and our scope of work was two-fold: conduct summative studies of the three exhibits, and conduct a study of the partnerships. We conducted summative studies of each of the three exhibits and provided written reports on each to project leadership. We also conducted interviews with data artists, computer scientists, ocean scientists, and Exploratorium staff who made up the exhibit development teams, and we prepared a report on the findings from those interviews. In addition to these main foci of our evaluation work, we also carried out some limited tracking of the reach and contribution of the project to the broader fields of informal STEM education and data visualization, by conducting interviews with STEM professionals that project leadership had interacted with at conferences where they presented work on the Living Liquid Project. We also prepared a report on the findings from those interviews.

Overall, the evaluation set out to answer the following key questions:

- What is the nature and quality of the partnerships between informal science educators, computer scientists, and research scientists? What are the important lessons learned from these partnerships that could inform the broader field of informal science education and broader outreach efforts of scientists?
- What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships? In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data? What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?
- What are the key lessons learned generated from this project about how best to design visitor interactions with large data sets for optimal opportunities for inquiry, questioning, and analysis on the part of the visitors?

This executive summary report highlights the major findings from our evaluation work on the project. We have organized these findings into the following sections: findings about how the project increased the capacity of STEM professionals to develop visualizations through collaborative development (which includes findings from our study of the partnerships); findings about the extent to which the project helped to advance public understanding of ocean ecosystems and large data inquiry skills through visualization (which includes findings on the visitor experience and outcomes); and findings about the extent to which the project helped to advance STEM professionals' knowledge of engaging the public in inquiry with visualization through an educational research study (which includes lessons learned about the project -- the particular design challenges the project faced, and about the project overall). For more in-depth analysis of our methods, and detailed findings related to each of the exhibits, and from the partner and other professional interviews, please see the attached individual reports.

Increasing the Capacity of STEM Professionals to Develop Visualizations Through Collaborative Development: The Nature and Quality of, and Lessons Learned from, the Partnerships

In this section of the report, we summarize the key findings about the partnerships.

- **The interdisciplinary partnerships were well-facilitated and, for the most part, successful.**[1]

In general, the partnership teams for each of the three exhibitions worked well together, in large part because the project leaders facilitated the work well, establishing domain boundaries and responsibilities based on people's expertise, and making the decision making process clear. Partners were actively involved throughout their work on the project, through frequent meetings at the Exploratorium, and in particular, in hearing about the research and formative evaluation findings. In only one instance, there were communication issues with one outside contractor that led to a less-than-satisfactory partnership experience.

Project leaders implemented a three-phase development process with the partners. Phase one was the research phase, where researchers and scientists identified the key questions that would guide the exhibit; data scientists and Exploratorium media developers, with support from scientists, envisioned the experience with the visualizations for visitors; internal evaluators conducted front-end evaluation; and everyone engaged in brainstorming. Phase two was the design phase, which involved all team members continuing to brainstorm, and individuals working on specific pieces for the exhibits; and the building and formative evaluation of prototypes. Phase three was the final build phase, where final decisions were made by the whole team on visualization aspects and graphics, and the science content; and final formative evaluation of the exhibits was done.

The other professionals we interviewed who had interacted with project leaders at conferences were impressed by and interested in how the project leaders structured and facilitated the partnerships. Several people we interviewed (who represented informal STEM education, evaluation in informal STEM learning environments, and data visualization fields) thought it would be beneficial to the broader fields of informal STEM learning and public engagement with science/communicating science for the project to

[1] We conducted telephone interviews with thirteen partners -- three scientists, five computer scientists, three data artists and two Exploratorium staff members. We conducted telephone interviews with six (of ten) other professionals. For more evidence and supporting detail for these findings, including our methods and detailed quotes from team members, please see the Living Liquid: Partner Interview Summary report and the Living Liquid Other Professionals Interview Summary report.

share not only its research findings, but also the processes of how the partnerships were formed and facilitated**.**

- **Embedded partners valued the project, and gained skills and knowledge that benefit their own work.**

Partners valued the multi-disciplinary team, the brainstorming sessions and the decision-making and prototyping processes that were a regular feature of the work. They appreciated the effort the project leaders made to share knowledge and best practices from the data visualization field that they could apply to their work on this project, and they valued the fact that the project was contributing to the field. There were benefits of participating for people representing all the different disciplines: data artists, computer scientists, and exhibit developers learned ocean science from working in-depth and over time with the scientists, while scientists and computer scientists learned about rapid, iterative prototyping, designing for a wide audience range in an informal learning environment, and everyone learned more about how best to communicate complex science to the general public. The following quote from one computer scientist highlights the value of participating in the project,

> *In computer science we normally invite other students or friends, not the public. Normally when we do user studies we expect people from 18-50 year olds, but in museums we need to explain things to kids under 8. So this was really rich and rare in terms of a PhD program. I'm really thankful to have the opportunity. It would be better if there would be more of these projects, to work with research labs where you need to make real things that people can use and everyone can understand.*

Importantly, partners we interviewed also noted that what they learned through their work on the Living Liquid project was contributing positively to other work. For example, data artists learned about how best to scaffold informal STEM learning experiences, and what makes a good data visualization. Scientists learned more about how best to communicate their work to the public, and where the specific barriers are when it comes to visitors interacting with large data sets and visualizations. In addition, several scientists talked about how the partnership had opened up more possibilities for them for utilizing different vehicles, such as visualizations, for interpreting their science research for the public. The Exploratorium is also continuing conversations across the museum (and beyond) about how to do good exhibit work with data visualizations.

Advancing Public Understanding of Ocean Ecosystems and Large Data Inquiry Skills Through Visualization: The Nature and Quality of the Visitor Experience, Inquiry and STEM Learning

Our goal with the summative study of the exhibits was not to replicate or duplicate the research studies, which explore the visitor inquiry experiences in very detailed and specific ways. Our key summative evaluation questions pertaining to the visitor experience with the exhibits were: What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships? In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data? What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?

The anticipated outcomes for visitors to these exhibits were originally identified in the project proposal as:

- Visitors are interested in the topic of ocean environments and marine life
- Visitors pose productive questions answerable with the database
- Visitors answer their questions by using the visualization to look at the data
- Visitors look at different variables and relationships
- Visitors interpret the data to identify patterns in marine life and environmental factors
- Visitors understand the connections between marine life and their environment
- Visitors have an awareness that scientists study oceans by collecting and analyzing data

Overall, we found each of the three exhibits had varying degrees of success in achieving the project's desired outcomes; this makes sense given the differences in data sets and content for each of the exhibits. In this section of the report, we summarize the main findings from our summative evaluations[2] of the three exhibits.

[2] Our summative evaluation work for each exhibit generally included naturalistic observations, mediated interviews, and exit interviews. For Plankton Populations, we conducted naturalistic observations of 59 visitors, mediated interviews with 21 visitors, and exit interviews with 11 visitors. For Mapping Migrations, we conducted naturalistic observations of 59 visitors, mediated interviews with 22 visitors, and exit interviews with 10 visitors. For Sea of Genes, we conducted 56 naturalistic observations, and 13 mediated interviews. For more detailed findings on each of the exhibits, see the three summative exhibit reports attached.

- **We found visitors were interested in marine life and ocean environments.**

With regard to our key evaluation question about the nature and quality of visitors' interactions with the exhibits, and the project's projected outcome about visitor interest in the topic of ocean environments and marine life, in general, visitors we observed and spoke with were interested in marine life and ocean environments.[3] We believe the exhibits, particularly Plankton Populations and Mapping Migrations, had some, though limited, positive effect on visitors' interest. For example, for Mapping Migrations, slightly less than half of the visitors we conducted exit interviews with noted that spending time with the exhibit had influenced (a "4" rating on a 5-point rating scale where 1 = no influence and 5 = great influence) their interest in ocean environments and marine life. We suspect these numbers are not higher because people approaching the exhibit may have already had at least some interest in the ocean and marine life. In contrast, for Sea of Genes, in mediated interviews, four of the visitors we interviewed expressed an interest in the content of the exhibit during the interview, and one young visitor we observed returned to the exhibit, bringing her father to look at it with her. However, given the limited amount of time visitors spent with the Sea of Genes exhibit in general, we are unsure the extent to which it impacted visitors' overall interest in ocean environments and marine life.

- **We also found it takes visitors some time to begin to understand what they are looking at in a visualization.**

For our naturalistic observations, we tracked the total time spent at the exhibits:

	Range	**Mean**	**Median**
Plankton Populations	4 seconds to 320 seconds	78 seconds	51 seconds
Mapping Migrations	2 seconds to 282 seconds	97.9 seconds	76 seconds
Sea of Genes	2 seconds to 89 seconds	22 seconds	9 seconds

With these exhibits, in this free-choice learning context, visitors had to quickly engage with new technology, as well as the visualizations, which are novel to the visitors, and then decipher how to interact with them and start their explorations. With Plankton Populations and Mapping Migrations, visitor time spent was long enough to begin to have engagements where they could notice patterns and ask and answer questions of the data (we discuss in more detail the reasons these two exhibits were more immediately accessible under the next bullet). This was not the case with Sea of Genes, where the short time of the exhibit usage coupled with difficulties navigating and understanding what they were seeing (which we investigated through mediated interviews) made the more in-depth investigations the project hoped for not possible.

[3] See page 8 in the Plankton Populations report, page 13 in the Mapping Migrations report, and page 5 in the Sea of Genes report.

- **With regard to the following projected outcomes -- visitors pose productive questions answerable with the database, visitors answer their questions by using the visualization to look at the data, visitors look at different variables and relationships, and visitors interpret the data to identify patterns in marine life and environmental factors -- we saw differences among the three exhibits.**

Mapping Migrations and Plankton Populations were generally more immediately accessible to visitors than Sea of Genes. And through Mapping Migrations and Plankton Populations -- many visitors met the goal of noticing patterns and asking questions based on the data visualization. With Mapping Migrations, visitors are familiar with maps of the Earth, and also with the large, charismatic species that were presented in the visualization.[4] These factors made the content more accessible, and so visitors could more quickly start inquiries and investigations. Similarly, the Plankton Populations visualization presented content about an at least sometimes-familiar topic (plankton). And, again, the content was displayed in the context of a map of planet Earth, which was accessible to visitors. This allowed them to be able to more readily start exploring the variables (levels of nitrogen, silica and light; time of year; types of plankton), and to make some guesses and hypotheses about what was going on.[5]

However, with the Sea of Genes exhibit, the topic and content were less accessible. The majority of visitors did not spend enough time at the exhibit to be able to think about and explore the abstract concepts presented (genes, gene activation, and their influence on the behavior of microscopic organisms).[6]

- **With regard to the project's outcomes -- visitors understand the connections between marine life and their environment, and visitors have an awareness that scientists study oceans by collecting and analyzing data -- we found that the fact that the visualizations were the distillation of large data sets wasn't always obvious to visitors**.[7]

At the Plankton Populations table, some visitors noticed the diagram in the upper left hand corner of the exhibit that shows a boat and illustrates how plankton is gathered. None of the visitors we spoke with made a connection between that diagram and how the larger data set was gathered, processed, and brought to life in the visualization (though we did not ask them explicitly about this process). When we asked whether they were aware that the data was "real data," visitors assumed that yes, the

[4] See page 9 of the Mapping Migrations report.

[5] See pages 8, 9 and 12 of the Plankton Populations report.

[6] See page 7 of the Sea of Genes report.

[7] See page 9 of the Plankton Populations report, pages 11 and 12 of the Mapping Migrations report, and page 10 of the Sea of Genes report.

visualization represented real data but they did not necessarily understand where, when, or how the data was gathered, compiled, analyzed, and ultimately presented.

The same was true for Mapping Migrations. Some visitors noticed the text in the upper left hand corner of the table that described how scientists collected and shared the data, but understanding how large data sets are rendered into a visualization accessible to the general public was largely missing for visitors. While they grasped that the data represented was "real" or authentic data, they did not grasp what was involved in or the complexity of transforming data collected across multiple animals in multiple studies into a single visualization. For the Sea of Genes exhibit, any discussion of the process by which data was gathered, processed, and turned into the visualization was largely absent for the majority of visitors.

Those visitors who understood that the Plankton Populations and Mapping Migration visualizations were from large data sets had additional questions such as: was this data gathered over one year? Is it the average of several years? What year was it gathered? Questions of this nature were generally not answerable using the exhibits. For Sea of Genes, visitors spent their time trying to decipher the visualization and did not get to the stage of thinking about the data underlying the visualization.

Advancing STEM Professionals' Knowledge of Engaging the Public in Inquiry With Visualization through an Educational Research Study: Challenges and Key Lessons Learned from the Living Liquid Project

In this section of the report, we summarize the key lessons learned from the project, about the exhibit development and key challenges, and about the project as a whole.

<u>Challenges</u>

- **The table technology**

Project leaders opted to go with table technology for the three exhibits. There were hardware and software issues and challenges; for example, the table had to be recalibrated several times as the self-calibration did not work as well as it needed to, and the table was overly light sensitive.

More importantly, we wonder about the extent to which choosing this one format for all three exhibits was limiting. Would it have been more effective to let the nature of the data sets, and the scaffolding required to help visitors to access and understand the data they were interacting with, dictate the medium through which the interactions would occur? Are there other formats that might be more effective in meeting the project's goals and enabling visitors to engage in inquiry? Would a different format

have worked better for some of the data sets? As one informal STEM education professional we interviewed who has some expertise and knowledge in working with data visualizations said,

> *We don't know how to use complex data sets in museums yet or even if they should be used. We don't know what type of interface is best for lay users.*

- **Working with three different, complex data sets**

Each of the three data sets brought its own challenges in terms of creating inquiry experiences for visitors within the table technology format. As we said in the visitor experience section, some of the data sets (plankton and migrations) lent themselves more readily to an inquiry-based data visualization exhibit because of having elements of familiarity for visitors that helped them more immediately interact with the visualizations. Perhaps most importantly, because the data sets were so different, the lessons learned and implementation strategies for designing visualizations that visitors could do inquiries with didn't necessarily always translate from one data set to another.

- **Low data literacy among the public**

As we stated earlier, we observed in our interactions with visitors—and the professionals we interviewed who have worked with data visualizations in informal settings agreed—that not many visitors understand what it means to make sense of data visualizations. For example, visitors might understand that data can be displayed in graphs or charts, but it is a leap for them to understand a complex computer visualization. So asking visitors to do investigations with data visualizations in a museum environment proved to be very challenging. As one data artist who worked on the project said,

> *The data set is so complex—how do you help people with very little ideas about data to work with it?*

Another professional we interviewed said,

> *Scientists are fluent in it without being conscious about it in their training, and it is hard for them to understand that you can't just put these visualizations out to audiences and expect them to understand.*

All of this raises the question of what foundational work might first need to be done with visitors around what a large data set is, and what does it mean and look like to create visualizations with that data, before the inquiry experiences can happen.

There is still much to learn about which foci might best be able to get visitors quickly into the exhibits, and the scaffolding needed to support them in understanding what they are seeing and how to interact with the data. And, these strategies might vary from data set to data set. As one other professional we interviewed noted,

> *The audience is unfamiliar with the topics, and so the project was dealing simultaneously with profound knowledge-base gaps. How much do you focus on building up a visitor's basic understanding about how sharks migrate... and then adding this super cool way you are interacting with the tech and have your own discovery... I wonder if we may have learned more if we had started with data sets where people coming had some foundational understanding of the principles... then you may have been able to unpack more on how the technology interface enables their understanding through interacting with the data.*

- **Staff turnover**

The project attracted highly qualified people, but there is a lot of competition in the Bay Area for skilled computer and technology workers. Many of the project staff were recruited away from the project by higher-paying technology companies. Staff turnover impacted the project when computer scientists and data artists left for more lucrative jobs, and new people had to be brought on board and up to speed.

<u>Lessons Learned</u>

- **The Living Liquid project was a very challenging, ambitious and complex undertaking**.

Utilizing new technology and visualizations to share large ocean data sets gathered by scientists with visitors in such a way that visitors could engage in inquiry experiences with the data in an informal science learning environment was challenging.

- **There are internal and external contexts that are important for understanding the outcomes of the project**.

Internally for the Exploratorium, this was a different kind of project. The Exploratorium's model is phenomenological, where visitors come to understandings through physical interactions with phenomenon that lead to self-guided discovery. This model is not one that applies easily to data visualization, where visitors may not have enough basic information or data literacy to be able to decode what they are seeing. And the external context is that the use of data visualizations in museums is somewhat limited, and there are even fewer attempts involving inquiry experiences.

- **For the informal STEM field in particular, there is little research or knowledge about how best to engage visitors with data visualizations on the museum**

floor. And fields beyond the informal STEM education field can benefit from lessons learned from this project.

Because there are so few examples of museum exhibits dedicated to visitor inquiry through data visualization, and few efforts to conduct research into these efforts, the project's rigorous research is valuable to the field. As one advisor to the project noted, "the project generated juicy questions for the field." These questions are ripe for further exploration and research. In addition, the project's efforts to disseminate what they've learned, through several research studies, and presentations at AERA, and a Gordon conference on data visualizations, among others, are noteworthy. Other professionals we talked with were grateful for the project's work sharing what it has learned. What more could be done to share specific elements of the lessons learned from the project, research and evaluation in ways that can be easily digested and shared again by others (e.g., two-page white papers on the partnership side; additional conference presentations; web blogs)? Professionals we interviewed were particularly interested in two-page briefs with key findings.

In addition to the museum field that needs both examples and research on working with visualizations of large data sets on the museum floor, there are professionals in other fields who can benefit from knowledge sharing from the Living Liquid project as well. Examples include scientists who care about sharing their work with the public, and computer scientists who are interested in learning about how their work is used and interpreted by their audiences.

Summary

Data visualization work is becoming more prevalent in our world, and as the informal STEM education field continues to dip its toes into how to bring data visualizations onto the floor in ways that encourage visitor investigations and inquiry, there is a continuing need for experiments and research for the field. The Living Liquid project was a good start at digging more deeply into how to translate best practices in data visualization into powerful science education experiences for visitors. The project produced three exhibits, learned a lot about what works well and what doesn't, and shared its research findings in multiple ways. Perhaps most importantly, they produced a model for developing and sustaining multi-disciplinary partnerships. While the three exhibits were not uniformly successful in facilitating in-depth investigations, there is value in the project taking on this challenge, and in generating additional questions for the field to continue to investigate.

Living Liquid: Partner Interview Summary
Inverness Research, Inc.

January 2018

Inverness Research conducted telephone interviews with partners in the Living Liquid project who worked as embedded team members and key Exploratorium staff who worked on the project. We conducted an initial round of partner interviews in January and March 2016 with three partners and one staff member, and another round of interviews in December 2017 with 11 embedded partners and two staff members (three of the 11 were partners we interviewed in 2016). Embedded partners included three scientists, five computer scientists, and three data artists.

All of the partners we interviewed found their participation in the Living Liquid project to be very valuable. They valued being part of a multi-disciplinary team, engaging in the rapid prototyping and research process, and working to both apply and add to the best practices in the field with regard to data visualization for informal STEM learning audiences. They also identified challenges the project faced and how they have continued to apply what they have learned from their work on this project to other projects and work.

This document summarizes the main themes from the embedded partner and staff interviews.

STRENGTHS OF THE PROJECT

- **All of the partners agreed that the partnership between ocean scientists, Exploratorium exhibit designers, researchers and evaluators, and data visualization scientists was very worthwhile.**

Partners valued the multi-disciplinary team, and the brainstorming sessions and decision-making processes that were a regular feature of the work. They noted that the facilitation of the teams was excellent, and they could see these ways of working being beneficial to tech companies and other work places.

> *Why don't we have more academic researchers working with real world products? Industry and academia have a lot to teach each other.*
>
> —Computer scientist

> *It was a pretty big collaborative experience, with a lot of really clever people, and it was a pretty rare opportunity for me. You don't feel scared to share ideas. It did help me learn, in an environment where you have a huge brainstorming session, how to share your ideas without clashing with other people's ideas.*
>
> —Computer scientist

> *I love working in these kinds of multi-disciplinary partnerships. One of the things I am reminded of over and over is the importance of understanding and respecting different domains—just because you are really smart in your own domain doesn't mean that you are going to know anything about someone else's domain. It is a very rewarding challenge when you can get a highly effective team where everyone can contribute and recognize the limits of their expertise and defer to the experts in that domain.*
>
> —Scientist

> *I learned a lot! The pace of development was awesome, and learning how to work in a development team was great. We would have many brainstorming and design sessions, and learning about the dynamic with five very vocal people, learning how to compromise...*
>
> —Computer scientist

> *There is definitely value in these kinds of teams. Everyone on that team had a different background and view on what the priorities are; everyone had their own backgrounds but they overlapped in their concerns. In every tech company, you need multi disciplines to come together—if the team is too narrowly focused they might miss other priorities. It makes it stronger when you have lots of different views...*
>
> —Computer *scientist*

> *We had a lot of meaty, in-depth conversations about how to best do the work.*
>
> —Data artist

All of the partners we interviewed complimented the PI and Exploratorium researcher on their facilitation of the partnerships:

> *I think Jen and Joyce did a nice job of establishing and maintaining the domain boundaries, and also who had the ultimate responsibility for picking directions and decisions based on their expertise. You may not make everyone happy all the time but you need to imbue the right people with the right authority at the right moment.*
>
> —Scientist

> *I am quite used to actually establishing partnerships and not having it work, but Jen was so together and had such vision that I immediately felt that it was a really good partnership.*
>
> —Scientist

- **Partners valued learning more about and applying best practices in the field to the work, and adding to the knowledge of those best practices through their work on the Living Liquid project.**

Partners appreciated the effort the project leaders made to share knowledge and practices from the data visualization field with the embedded team, and they valued the fact that the project was contributing to the field.

> *It was exciting to be able to feel like we were really taking the time to try to apply the principles and the kind of knowledge of the field to the work we were doing. It wasn't always an easy thing to apply, but we were trying to figure out what the field thinks is a good approach and apply it in different ways.*
>
> —Exploratorium staff person

> *I learned a lot about how to develop a good data visualization and what are some things that work well or work less well. I feel like I learned a lot about how to represent things and which kinds of representations are appropriate for different tasks, like using color for this kind of thing or the size of something for this kind of thing...*
>
> —Data artist

> *We were playing a lot with abstractions of data and this kind of spectrum of making things seem interesting but not too technical (vs. technical and not interesting) and the continuum between those two... we tried lots of different things along that spectrum. It was good to build up an intuition about where the line is and that is useful for future work.*
>
> —Scientist

- **Partners valued tackling the design challenge the project presented, and not shying away from it, particularly with the Metagenomics exhibit.**

Partners we interviewed commented on how difficult the challenge was, of translating large data sets into exhibits that visitors could interact with and do inquiry with. This was particularly true of the Metagenomics exhibit. Partners also commented on how proud they were of the fact that no one shied away from that challenge.

> *Working on the Metagenomics exhibit was a real challenge... I knew it wasn't going to be easy, but I am proud that we gave it our best shot... even if we didn't come out with total success.*
>
> —Data artist

> *I am an interpretation person and thinking about how to talk about these things to visitors who aren't bringing a lot of outside knowledge, I knew from the outset it was going to be a challenge. While people have developed better understanding of what genes are, I think the idea of gene expression, and that you could study that as a way to understand the ecosystem, those were very unfamiliar concepts. I could tell it would be a big challenge for visitors to figure out what we were trying to show them, let alone for them to be able to look at the data and see what's there. I knew we were trying something difficult.*

—Exploratorium staff person

> *The main challenge was just the idea that this is Metagenomics; most people don't know what it is let alone have a mental model or something tangible to understand it. My mom is a biology teacher; even she hadn't heard of it. Not sure of what the starting point should be. We decided on having a simulation, what it is and why it matters. Why this opaque concept applies to the real world; [we used] character, animation—more friendly characters than a microscopic spec… We wanted people to be able to interact, but we found that people were fixating on the ability to add or subtract organisms but that is not what the data is about. The data is about the fact that the microorganisms do exist and interact with each other.*
>
> —Data artist

- **Partners and Exploratorium staff valued working in-depth with the scientists, and learned a great deal about the science being presented.**

As one Exploratorium staff member said,

> *Working with the outside scientists was really interesting. It is always great to work with experts in the field who could really talk with us in depth about their work and research. I feel like Randy Kochevar was incredibly generous with his time. He came to the Exploratorium on a number of occasions and presented the research to staff. I feel like partnering with the scientists, we were able to ask them for different data sets, or for more data about this. They knew how to get it, how to work with their colleagues to help us get what we need.*

And as one of the data artists noted,

> *I would say that the most rewarding thing in working with the Exploratorium is the opportunity to learn while you work, and so I learned a lot about Metagenomics and about how different kinds of classes of organisms participate in the, sorry, my terminology is a little rusty at this point, but in the metabolic food web for lack of a better way to describe it.*

- **Scientists and computer scientists learned about rapid prototyping and iterative product development for an informal STEM learning environment.**

While computer scientists engage in product testing in some ways, the kind of rapid prototyping and iterative exhibit development that the Exploratorium engages in is quite different. Computer scientists valued observing visitors, hearing about the evaluation and research findings, and learning from the process of prototyping.

> *Coming from an academic background, I hadn't really worked in a team that did that type of iterative development before, where you prototype, get feedback, prototype, get*

feedback, and that cycle goes on for a while. In the academic world, it's more, "here's an idea; we'll present and do a paper."

They appreciated the nimbleness of being able to create a prototype and put it out on the floor for visitor testing quickly.

What makes the Exploratorium special is they have such a thin barrier between creating something and showing it to people... you spend a day on something and put it on the floor. In a lab or in industry, it is a much heavier-weight process where to get user testing and feedback, you have to create a whole user study, get that approved by IRB which can take months. And in industry, there are non-disclosure agreements to sign, and you have to run everything by PR to make sure you aren't affecting the brand...

The computer scientists and data artists, in particular, valued being able to observe visitors interacting with the products they were contributing to.

I really get a lot out of seeing visitors interact with things that I design and build. They are just not making something and pushing it off into the void, like you might do if you are building for the Internet. Getting to have interactions and conversations with people and seeing what they are actually taking away from it, and then feeding that back into your design process so you can improve the thing that you have created is a nice opportunity that doesn't exist in a lot of other contexts.

In computer science we normally invite other students or friends; not the public. Normally when we do user studies we expect people from 18-50 year olds, but in museums we need to explain things to kids under 8. So this was really rich and rare in terms of a PhD program. I'm really thankful to have the opportunity. It would be better if there would be more of these projects, to work with research labs where you need to make real things that people can use and everyone can understand.

I think that working with the same data in other contexts helped me appreciate, reminded me that the final product is so driven by context. When you are talking about the Exploratorium setting where you have visitors in a free form experience, walking up to the table and you engage them in content it's different than students in a classroom. They are going to engage differently. Even though the data are the same, the experience you create will be completely different. It feels like a really good case study for how the design is driven by how it will get used and not by its component parts.

And almost everyone who participated commented on the thoroughness of the process, and how much that contributed to learning a great deal from participating in the Living Liquid project. As one of the scientists said,

I have been involved in other education programs using these data and also in other exhibits, but in none of them did I learn the same kinds of things. I attribute that to the

process that we were going through, which was very self-aware. It was unique in how painstaking and methodical it was. At every step we were actively questioning… what does the visitor think? What is the meaning they make from what they are seeing or doing?

- **Partners said their involvement on the Living Liquid project has influenced their other work.**

  The exhibit environment is difficult to design for; it's unstructured, random, unguided. I would say that seeing how people interact with things, you have to provide the right scaffolding. I use that concept now.

  —Data artist

  I think the project helped me really understand what goes into a public visualization, compared to like a scientific visualization. It taught me how to be a better designer for educational visualizations.

  —Data artist

  Getting to see the data that I worked on for a decade, and seeing them visualized and shared in a number of different ways is very exciting. Seeing some new idea or thought or concept about how we can share it has been really intellectually interesting for me as a person who is concerned about data visualization in general.

  —Scientist

  There is another NSF-funded project I am involved with called Ocean Tracks. We are using the same data and we are building a learning experience for high school and undergraduate students, exploring relationships between animal migrations and the surrounding environment in terms of temperature, currents, chlorophyll… things like that. It is an interesting interplay between projects because it's the same data set. It has different audiences, different learning objectives, but lots of intellectual cross-pollination between the projects in terms of thinking about problems faced when talking about this kind of data and what tends to trip people up. Working on Living Liquid has informed the thinking on Ocean Tracks and vice versa.

  —Scientist

One of the scientists talked about how the color palette of the visualizations was adapted to not confuse the visitors, where "red" can mean warm to a visitor when that was not what the scientists or visualization was meant to convey. She also shared some lessons learned about symbols that worked, and that have translated into other projects.

> *A lot of our visualizations now have very different palettes and I think that was a very useful thing to have learned.*
>
> *One of the other things that we worked on with them was, when you look at the little magnifying glasses, it tells you what temperature it is and what the nutrient concentrations and things are in certain regions, and it is quite a difficult concept to explain to people. Working with them on how best to show those environmental factors to the people coming through the Exploratorium gave me a little bit more of a sense of*

how people get the information and where it is confusing and so I think it may be a little clearer in how to explain things to non-scientists.

Partners also talked about how much they learned from watching the visitors interact with their visualizations and how that has been motivating in addition to informing their other work. One of the scientists said,

I actually found it really fascinating to sit there and watch that table because I could actually probe my model in a way that I can't normally. All of that stuff is actually numbers in the end, you know, and I look at the numbers more than I look at the pictures, if that makes sense. So I do visualizations, but really they are just visualizations of the numbers. The interactiveness of this was just wonderful and so it gave me a completely new way to look at my own work. And to see other people excited made me feel even better about what I do.

Three scientists talked about how the partnership had opened up possibilities and re-invigorated their interest in their science.

We scientists sometimes are not so good at communicating and so seeing other people communicating and learning how they communicate was definitely a good thing to have learned. Also, seeing some of the folks who were really great at animations and seeing what they could do, at least gave me the idea of what could be done. I hadn't even thought about going in those sort of directions beforehand and so I think seeing how Isaac thought about a problem and how he tackled it and what he was capable of doing was, I am not sure it has changed anything that I do with regard to my science, but it certainly opened up some possibilities to me or at least some understanding of what is possible.

I think it is just the excitement of the science, and seeing how other people can be excited about it... and that made me excited about continuing my science. And then just working with people in completely different fields to what I normally do and so that interdisciplinary context was very valuable to me and I gained so much interdisciplinary knowledge.

Microbes, in general, are hard to communicate about—they are small, people aren't used to seeing them, when they do interact with them, it is usually something that makes them ill—so there are all kinds of negative connotations. We wanted to make sure visitors understood that microbes have these daily rhythms and do important things. It was validating to realize how difficult it was even in a room of people that have many years in communicating difficult things, and I haven't completely missed the boat for the past twenty years. It did give me new ways to think of analogies for people and how people interacted with what they saw... it helped me think about how I structure narrative and find ways that the narrative can be more approachable for different audiences.

The project has sparked conversations about how to do good exhibit work with data visualizations that are continuing. For example, at the Exploratorium, the PI has been organizing a data visualization group at the museum. As one Exploratorium staff member said:

> *Some things we have learned from this work, and things people have learned from other projects—and we have decades of experience on how to develop exhibits... and we have these best practices documents around that. I think this kind of work with data visualization isn't nearly as mature, but we all recognize it is an important part of our work going forward... if we can really learn how to work with data and how to help people understand it and investigate it, it will be valuable for our visitors...*

CHALLENGES

- **The Living Liquid project set a very high bar: utilizing new technology to share large ocean data sets with visitors in such a way that they could have inquiry experiences with the data in an informal science learning environment. Partners we interviewed agreed that almost every aspect of that was complex, and that complexity posed challenges.**

Visitors were tasked to figure out what data is, what the specifics of a particular data set were and what science learning could be gleaned from that, and then also tasked to do inquiry with that data. For starters, several partners wondered how much of a basic understanding some visitors had about what data is:

> *The data set is so complex—how do you help people with very little ideas about data to work with it?*
>
> —Data artist

> *Fundamentally, this project was looking at 'how do we get people to do inquiry around data?' What would I conclude? First of all, I would imagine it would be really awesome to do a future project that is helping people understand what data even IS. It almost seems like a meta project...*
>
> —Exploratorium staff person

Another challenge came in helping visitors to understand what a gap in the data means, or what the notion of time means in data visualizations.

> *One of the things we struggled with was the problem of when there is no data, how you represent no data or the limitations of the data set. Visitors would think like, 'oh, the animal died' or 'there is nothing in this part of the ocean.' There really isn't an easy way and I think this is an unsolved problem in the field of data, generally speaking.*
>
> —Exploratorium staff member

With the Plankton Populations, the exhibit plays around 6 years of model data on a loop and it was really difficult to convey the movement of time in addition to the motion of the different biomes moving through the ocean because of the ocean current. It was just really hard to annotate time, and for people to have an understanding of what speed things were occurring at in the visualization. A lot of it had to do with the fact that we couldn't find a way to put a representation of time in front of people's faces without distracting them from other things, like investigating what genomes were present or what different kinds of organisms are present at a certain location in the ocean.

—Data artist

In all of these data there is the fact that this is a track across the ocean; the thing that's easier to forget is the data associated. If you were able to animate all the tracks there would only be two or three points. Dealing with time in these data sets is a tricky thing. It's easy to overlook and it's complicated. Understanding the time element is confusing. And I think that another thing we dealt with is that people have expectations about things. When you are driving you can know exactly where you are at all times. Getting locations seems like a simple thing to do. For an animal traveling under the ocean it is really hard. Sometimes you can't. The other thing that comes out in user testing is that people's basic familiarity with maps is surprisingly lacking. Most people would recognize a map of the US, but when looking at a map of the ocean, not so much...

—Scientist

A lot of data visualizations, they tend to focus more on quantitative representation of data, like a line chart that shows you specifically what this value is at this point in time, but that is not really valuable for understanding Metagenomics in the context of ISE. I think it is more about understanding qualitatively how these microbial communities interact with one another and with their environment and how they take in input from the environment and how they send out changes into the environment. That is going to be legible to someone who is not a scientist because you aren't looking at it quantitatively. So we have this kind of simulated environment in which these data-informed characters would move around and interact with one another to create this qualitative sense of the science. So, I guess in terms of informing future work, I think it is a good technique to sort of set up that kind of sandbox environment when trying to convey a qualitative sense of the data rather than a quantitative sense. It is a technique that we developed for these two pieces and I think it works well in that context.

—Data artist

A challenge came in how best to facilitate the visitors engaging in inquiry with the data:

The kinds of scaffolding that are required is another thing we experimented with a lot in terms of helping visitors do inquiry with the data. How do we help people ask the right kind of answerable questions? We tried a lot of seeding with questions, providing example questions, making it so you could just watch and find something out... and that varied by data set, so it isn't easy to say what the right way to do this is…

—Exploratorium staff member

We found that in order to foster inquiry we had to find a non-linear non-narrative experience. It remains challenging.

—Scientist

We are trying to make the interface as clear as possible; there is a wide range of audiences. We have learned a lot of lessons about how to make it more intuitive and engaging.

—Data artist

I think that a tendency of people who do exhibit development is to want to create a narrative, a storyline and experience that draws the visitor through the storyline. When we were thinking about the table we were creating the storylines we wanted them to follow. But when we gave them the signposts and experience narrative arc we dreamed up, we prevented them from getting off the road and doing the inquiry. It's about wandering around lost and making discoveries. So that is a tension. Now we are saying we want to let them do the inquiry to reach their own end point, which will be different for each person and equally valid.

—Scientist

For me, it was like there were two sides: do we want this to be about 'look how amazing metagenomics is,' about the process of doing this, like 'you can throw a bucket in the ocean and have a real-time stream of behavior'? Or is this about the ecosystem, specifically these organisms: 'look how interesting their relationship is.' It is too much to do both simultaneously. Both have almost zero entryway for laymen, and for either of those, just to explain it, you need full attention, and if you have to explain BOTH... what's a genome? The challenge was to get agreement: if we had to choose, which one would you want it to be? Is it: 'be a scientist, know what it is like to be able to see without seeing'? Or: 'be a genome and understand your role in this crazy ecosystem'? We did both and it ended up being a little muddy...

—Data artist

Still another challenge is that all of this is happening on a museum floor, where visitors range widely in ages, science literacy and backgrounds, and where there are other exhibit competing for their time. Figuring out how to hold the attention of visitors long enough to begin to move through all these varying degrees of complexity was another thing partners talked about.

I feel like audiences of visualizations on the web are somehow easier to design for, and I think you can add more depth and complexity to a visualization piece that lives on the web. On the museum floor you have people who are subject to a really wide array of stimuli and things vying for attention—from other people to their kids or their parents and to other exhibits and everything that is going on around them, like the general chaos depending on the time of day and day of the week of the museum floor.

—Data artist

- **Not all data sets are created equal when it comes to using them to create an exhibit encouraging visitors to do inquiry work with the data.**

Several partners noted the complexity and challenge in working with three different data sets. Some of the data sets leant themselves more readily to an inquiry-based data visualization exhibit than others. Importantly, lessons and implementation strategies the project learned from the development process with one data set didn't necessarily always translate to the other data sets.

> *Coming into it, I think we thought you take a data set and develop an exhibit in this way so people can do inquiry with it... but, you know, not all data sets are created equal and some of them lend themselves well to developing an inquiry experience about that data, and some really don't lend themselves as well to that kind of [inquiry]—so choosing your data set is incredibly important. I do know you can find yourself working with a dataset that doesn't lend itself to that kind of inquiry... and perhaps we should have done a different kind of exhibit with that...*
>
> —Exploratorium staff person

> *Every data set is so different. We tried a number of ways and I think the answer was different for every data set or visualization...*
>
> —Data artist

> *We did several versions of the Mapping Migrations and I feel like that was a real learning experience in terms of seeing what was it that we were trying to show. We had a goal of trying to create inquiry into the data and we had some starts on things that while they were interesting as exhibits, they didn't meet that criteria quite as well...*
>
> —Scientist

- **Partners we interviewed noted the complexity and the challenges of the project were compounded by the focus on answering research questions and the project timeline.**

Partners noted there were times throughout the project when the grant timeframe was not ideal for the complexity of the research and development challenges being addressed through the project. Partners wondered when they should stick to the research and proposal idea, and when they decide not to.

> *At various times through the project, we were struggling to hold the line of our original plan as challenges arose. From my perspective, I wonder if it would have been helpful to us to cut scope or change gears.*
>
> —Exploratorium staff member

With the short time frame of the grant, the complexity of the research questions and of the exhibit, it felt like there were times we were making a choice: 'this might not be the best for the public but we need to do it for the research...' so there were definitely some trade-offs there...

—Exploratorium staff member

The research aspects of the work were really exciting; the only caveat would be that the timeline was pretty tight with everything that happened.

—Computer scientist

- **One of the key challenges the project faced according to partners was staff turnover.**

Partners also noted the ongoing challenge of staff turnover. In particular, the project attracted high-quality people, but there was a lot of competition in the Bay Area for highly-skilled computer and technology workers among higher-paying technology companies.

We had a series of really high-quality students who were really enthusiastic about this work. They did an incredible job—most of them put in so many hours and were really committed to the project, and were really interested in learning with us about what we were doing, which is an important piece. These were all young people with incredible skills who would inevitably get jobs... so we'd have people leave mid-stream...

—Exploratorium staff member

Staffing this project was a challenge, in the sense that people on the Davis side came and went, people on the Exploratorium side came and went... coders came and went... It was a revolving door and there was a constant need to get a different person up to speed...

—Scientist

- **Partners also talked about the limitations and challenges inherent in the technology the project was working with.**

There were hardware and software issues, constraints and limitations that the project teams had to work around to try to ensure good visitor experiences. As two computer scientists noted:

Hardware was one big one. The Exploratorium is very NOT digital, and there is this resistance to incorporating new media. A lot of their exhibits are about exposing the mechanics of how some phenomenon works. They tend to not like a computer with mouse and keyboard because things are too hidden away. We didn't just want a computer, but an innovative exhibit, something you had to be physically present to play with phenomenon, to touch, change, and see how it reacts.. That led to why we went

with the whole multi-touch table, which is not common technology. So, finding a vendor was challenging, and then the table had issues and had to be recalibrated several times. I had to learn a lot of software techniques to filter out noise and compensate for a lot of those drawbacks. And then for the educational impact on the visitors, I think that was aided a lot by the text boxes around the whole exhibit; that context helped a lot...

The table was sensitive to light; it changed throughout the day, and it would interpret the touch differently depending on the contrast. The table was supposed to be self-calibrated, but it didn't work as advertised.

Living Liquid
Other Professionals Interview Summary
Inverness Research
February 2018

In an effort to document the ways in which the Living Liquid project contributed to the knowledge base of the field, in January 2018, Inverness Research reached out to ten professionals that have interacted with the project through conferences or direct contacts. Of the ten professionals we contacted, we were able to schedule and conduct telephone interviews with six (two of the other four did not respond, one did not wish to be interviewed, and the fourth was unable to find a time that worked for an interview).

The interviewees included the following:

- one person who acted as an advisor to the project
- an evaluator who has experience working on data visualization projects
- a data visualization specialist at a major medical school
- a computer science professor
- a director of an environmental science center
- an exhibit developer at a large science center

The professionals we interviewed ranged from people who had interacted with the project leaders at conferences and/or read research papers, to those who had seen the exhibit prototypes, to those who had a bit more knowledge of the partnerships and processes used to develop the exhibits. This brief report summarizes the key findings from our interviews.

- **Other professionals are very interested in the work and research of the Living Liquid project, and see this project as having an impact on their work.**

All of the other professionals we spoke with are interested in the results and lessons learned from this project, and see the results as making a contribution to their own work. They spoke of applying what they know from the project so far to how they think about their work. They also spoke of collaborating on other projects with the Living Liquid Principal Investigator. Even for those whose work with data visualization is quite different, they see enough overlap in the "grand ideas" of this type of work that they think the project has value to them:

> *[Jen and I] had lots of similar ideas about how to visualize information. My work is focused on a facility and discussion—how to have complex conversations with science and connecting people with information to make data-driven decisions. The work she was doing was very connected with that because she was also*

> *thinking about how to get information to people of different ages...so we have had lots of overlap in grand ideas.*
> *Jen has specific ideas about how the art and science of data visualization is working in the museum, but she can bump up to this other level or enter my world, so the sharing of ideas is really fun. I don't tend to get to the specifics of 'use blue instead of red' but I want to partner with someone who does that really well.*

One evaluator we spoke with was particularly interested in the project's findings about data visualization and inquiry:

> *There are projects I am working on that have data visualization components to them... and this project is interesting to me because if you are really trying to spend some time exploring, how does that change what you are trying to do?*

And one advisor to the project was excited by the number of questions the work of the project has raised, which she hopes the informal STEM education field and learning researchers will continue to explore:

> *This research project was the very tip of the iceberg. It created a whole bunch of really juicy questions that are valuable for the field...*

- **In particular, professionals working in the museum field are in need of any work that informs how best to utilize data visualizations in informal settings.**

Museum professionals, in particular, pointed out that there isn't much research or evaluation data on how data visualizations work in a museum setting, and because of that, they see the Living Liquid project as being "hugely important:"

> *Some of the academic work on data visualization struggles to understand the limitations of the environment of a museum experience, so I was glad to see another group working on that. It is good to see some of the data about that to understand what works and what doesn't... it is good to see that we aren't the only ones coming to some similar conclusions around experience and engagement before scientific accuracy... In some cases we are using techniques of visualization that are novel to the visitors, so they have to learn about the topic but also learn how to read a diagram they have never seen before...*

This museum professional shared some of what he was finding in the early stages of his own data visualization project:

> *There are definitely things that are more didactic and don't open themselves to exploration. One thing that we found with initial visitor studies is that if your ultimate goal is to tell a story with complex data, starting from a very simple*

> *point of view, and then building and layering on aspects of complexity, leads to better understanding... The other thing we are playing with is trying to pick data sets and/or stories for visualization that allow for personalization specifically. We are positing we might get people to understand a complex thing if the first thing they see in that is themselves: what visualization story can we tell that has your personal story reflected there? The other concept we are struggling with is around outliers in the data... for the lay consumers, it is hard to pick up what those outliers mean in a short visit to an exhibit. That is, is it meaningful in some way or just an error or a bad data point?*

And the advisor to the project simply said:

> *We don't know how to use complex data sets in museums yet or even if they should be used. We don't know what type of interface is best for lay users.*

- **In addition to the importance of the findings from the Living Liquid project for the museum field, other professionals we interviewed see a need for sharing the lessons learned and findings from this project beyond the informal STEM education field.**

Almost every professional we spoke with noted the value of findings from this project for a wide range of constituents they work with: for example, vendors, industry people, and outside exhibit development firms. As one professional said:

> *The Gordon Conference folks were interested in data for data literacy sake rather than data for data content things... There are a lot of industry people who are dealing with these same sorts of things. And I feel like sometimes we aren't necessarily reaching the right audience with the research on this work— the folks that need to hear this are not participating in those forums, and there are outside exhibit development firms that need to hear this too because most museums are developing their interactives outside.*

Two professionals we interviewed requested summaries of results that they could share with their clients and people in their specific fields:

> *Will they have a two-page round-up, like a more visual roundup of the results that are more applicable to others in the field that I could send to the clients I am working with on these types of projects? If something like that was developed, that included Joyce's rigorous research work as well as the evaluation findings, I could use that even more—I could send it to folks who are using it and have a larger conversation....*
>
> *Can the work that Jen and her team did be accessible to the outside world almost as a case study of how to do this? How can others learn from what they have*

gone through? I would pick that up in a heartbeat and there's not much of that around... How does that become disseminated and help inform other teams? In the final materials, there is often little or no meta-data that is associated with the final piece about why something is designed a certain way. If there is some way to capture this information, that would be really useful to others in the field who are struggling to make those same types of decisions in interdisciplinary projects.

One professional spoke of how little knowledge there is among the public about data visualizations and how they work:

There is low data literacy among the public and a profound lack of understanding of how to go from a graph to a visualization—that's a huge leap for most people... Data visualization is like a whole separate language and you have to learn to speak that language. Scientists are fluent in it without being conscious about it in their training and now it is hard for them to understand that you can't just put these visualizations out to audiences and expect them to understand. And the Exploratorium's model—phenomenological, self-discovery through physical interaction—is a difficult one to apply to data visualization... They don't want to put up this global visualization and provide an explanation as to what you are looking at; they want people to look at it and come to their own realizations. But people don't do that—they don't have enough basic information to decode it. We have a long road ahead of us to build that fluency if we want visualizations to be more a part of our regular language. I don't think NSF has invested enough in the learning research around data visualizations.

- **In addition to the lessons learned and findings being of value to other professionals, they also think understanding the partnerships and the processes behind the work of the design teams potentially could be valuable to others as well.**

  When I hear a bit about how they went about having this highly interdisciplinary approach that starts with real data—which is another thing that is a big deal and a big part of our work—the benefits of bringing multiple disciplines to this problem is great. I think of it as a project done right... It has guidance from the top from someone who understands the content but appreciates bringing multiple perspectives to bear... I would be interested in a case study of their team processes too.

- **There were two professionals we interviewed that had seen the exhibits and were more familiar with the overall project; their comments about the project reiterated some of what we heard from our embedded partner interviews.**

One professional acknowledged the complexity of the project, and many of the challenges the project faced:

> *There were big technology challenges, I think. I think they were dealing with very complex data sets and dealing with new technology that hadn't been tested in a museum setting. Those two things presented pretty big challenges for the projects. And then there was the added challenge of this self-discovery component—these were three really high bars to get over, already. And then they shifted data sets, and I don't know how much of what they learned they were able to transfer from the first one to the second one other than the technology. And in the background, the Exploratorium was going through major institutional changes, and there were significant team challenges in terms of personnel—being in San Francisco, they were losing their coders to all the big tech firms. Jen had really great, talented people but they were getting stolen away from her. What do you do as an informal science institution that can't pay what a tech company pays? There were a lot of things that were challenging.*

Another professional who had interacted with the exhibits wondered how much the table format influenced the visitor interactions:

> *I thought the exhibits were fascinating. I do wonder if it would change the interaction if they had tried a wall format vs. a table format.*

This same professional talked about how the different data sets posed different challenges, and the importance of letting the data dictate the format, to some extent:

> *Not all data sets are the same, and you can only take some lessons over so far. As we are developing materials for different audiences or for the same audiences using different types of data, you have to let the information tell you what is the best format within which it can live.*

Another professional wondered if a more narrowed scope of activity for the exhibit development might have helped:

> *The audience is unfamiliar with the topics, and so the project was dealing simultaneously with profound knowledge-base gaps. How much do you focus on building up a visitor's basic understanding about how sharks migrate... and then adding this super cool way you are interacting with the tech and have your own discovery... I wonder if we may have learned more if we had started with data sets where people coming had some foundational understanding of the principles... then you may have been able to unpack more on how the technology interface enables their understanding through interacting with the data.*

Living Liquid
Mapping Migrations Summative Evaluation Report

Inverness Research
July 2017

Introduction

The Exploratorium, a museum of science, art, and human perception, has partnered with scientists and data visualization specialists to create three exhibits around three separate large data sets that will allow visitors to interact with scientific data on oceans. Inverness Research is responsible for studying the nature and quality of the partnerships and network created by this project, and for conducting a summative evaluation of the exhibits and the project as a whole. As stated in the project's proposal to NSF, Inverness seeks answers to the following key evaluation questions:

- What is the nature and quality of the partnerships between informal science educators, computer scientists, and research scientists? What are the important lessons learned from this partnership and network that could inform the broader field of informal science education and broader outreach efforts of scientists?
- What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships? In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data? What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?

Inverness has been contracted to provide summative evaluation on three Living Liquid visualizations: Plankton Populations (PP), Mapping Migrations (also known as Tracking of Pacific Predators or TOPP), and Sea of Genes (also known as Metagenomics). This document summarizes the data collected for the summative evaluation of the second – the Mapping Migrations – visualization. (Inverness also conducted update calls with project leaders and interviews with Living Liquid partners. Those activities are not included in this summary.)

Evaluation approach and data sources

The outcomes for visitors, originally identified for these exhibits in the project proposal, are as follows:

- Visitors are interested in the topic of ocean environments and marine life

- Visitors pose productive questions answerable with the database
- Visitors answer their questions by using the visualization to look at the data
- Visitors look at different variables and relationships
- Visitors interpret the data to identify patterns in marine life and environmental factors
- Visitors understand the connections between marine life and their environment
- Visitors have an awareness that scientists study oceans by collecting and analyzing data

Desirable outcomes that the Exploratorium's Mapping Migrations team had identified just prior to summative evaluation follow:

Content

- Visitors will notice there are patterns to where marine animals go in the ocean.
- Visitors will notice animals go to certain places
- Visitors will notice animals go to these places certain times of year
- Visitors will notice there are differences in the places species go.
- Visitors will notice that members of the same species follow similar "routes" that may be very different from other species
- Visitors will notice that males and females can have different migration routes.

Skills

- Visitors will notice patterns in where animals go
- Visitors will ask a question based on the data visualization (e.g. "Do the tuna go to the same place turtles do?")
- Visitors will answer a question based on the data visualization

This report describes the extent to which and how these goals were met by visitors.

Data Collection

Inverness used three methods to gather data on the Mapping Migrations exhibit.

Naturalistic observations of 59 visitors interacting with the exhibits. To maximize the amount of data we could collect, we selected visitors for observation simply by choosing the next person who approached the exhibit, after we completed our previous observation. In other words, we observed one visitor and when we completed our protocol, we began observing the next visitor. We documented the time visitors spent at the table, the nature of their interactions with the exhibit, and the conversations visitors had with others as they used the exhibit. (See Appendix A for naturalistic observation protocol.)

Exit interviews with 10 visitors after they used the exhibit. We conducted exit interviews with a subset of visitors we observed naturalistically (those who stayed for two minutes or longer) in order to better understand their engagement with the exhibit, their conceptual understandings, and the questions they were interested in pursuing further. (See Appendix B for exit interview protocol.)

Mediated (think aloud) interviews with 22 visitors during their interactions with the exhibits. We approached the next visitor who was within a radius of ~20 feet of the exhibit, and invited them to use the exhibit. They confirmed verbally that we could talk with them as they used the exhibit, so we could better understand the nature of the inquiries visitors made with the data and the visualization, and the nature of their understandings of the data as they interacted with the exhibit. (See Appendix C for mediated interview protocol.)

The same one to two researchers collected data on a series of weekend days in February, to maximize the number of visitors who would be present (since school was in session during this data collection period, unlike the data collection period for Plankton Populations).

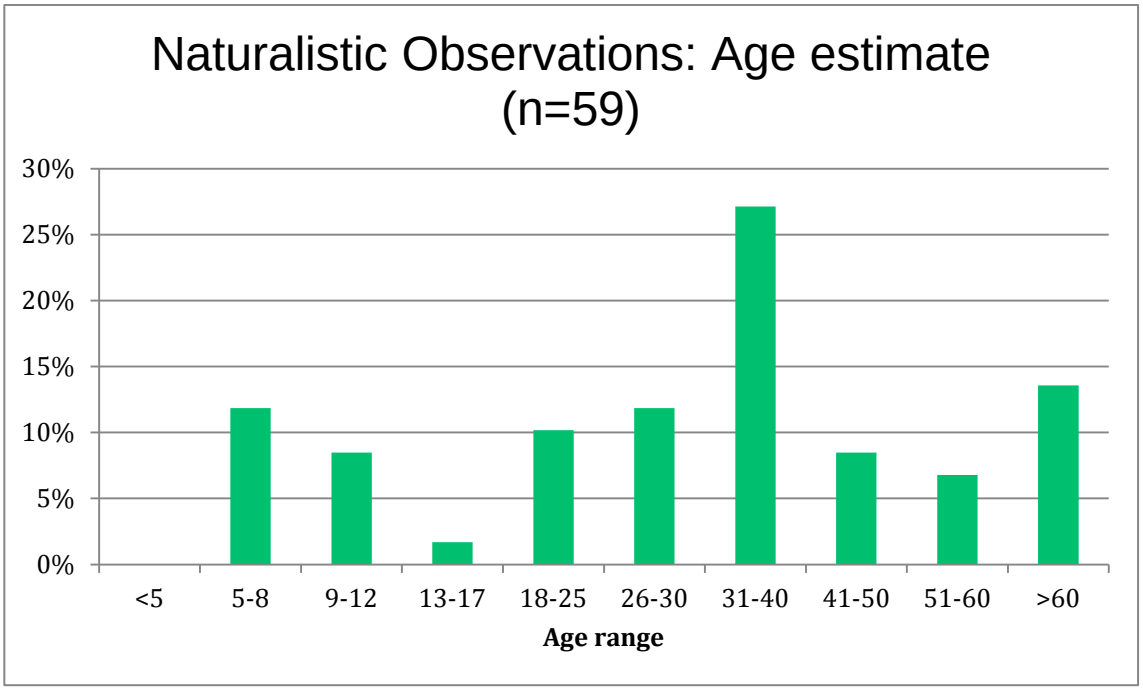
Data Collection	
Day	**Date**
Sunday	February 5th
Sunday	February 12th
Saturday	February 18th
Saturday	February 25th
Sunday	February 26th

Findings

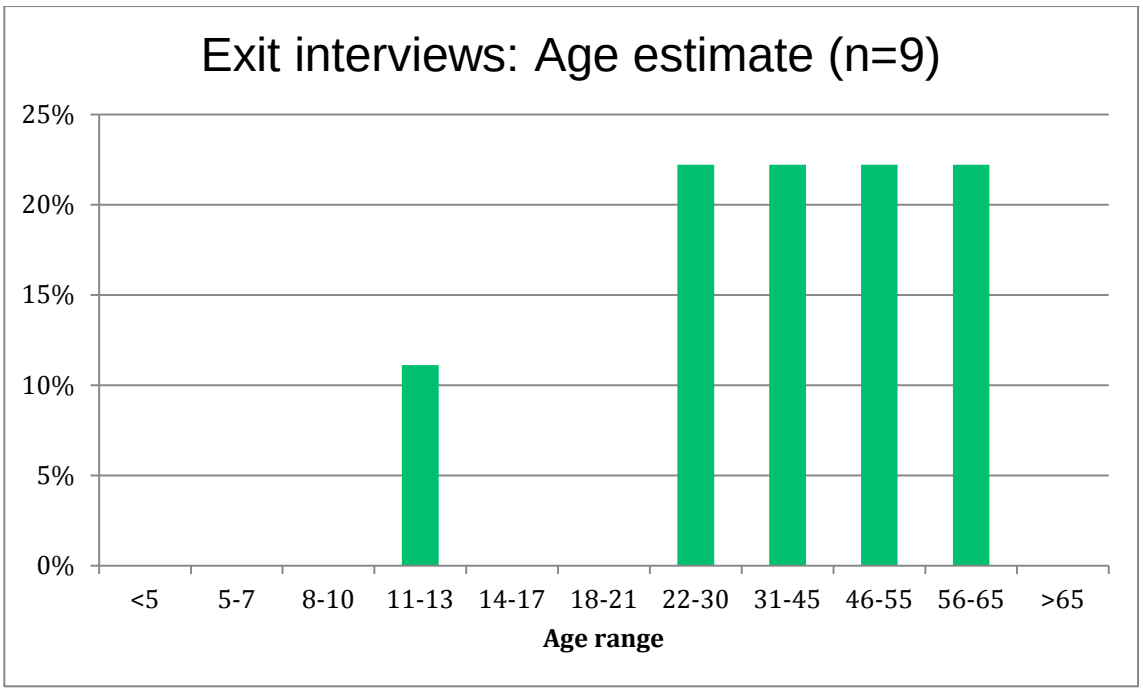
Following a summary of the demographics of the visitors involved in our data collection, we present our findings according to the following categories: overall satisfaction or enjoyment, invitation and navigation, inquiry and visitors' questions, and conceptual understanding.

Demographics of visitors, according to data collection method

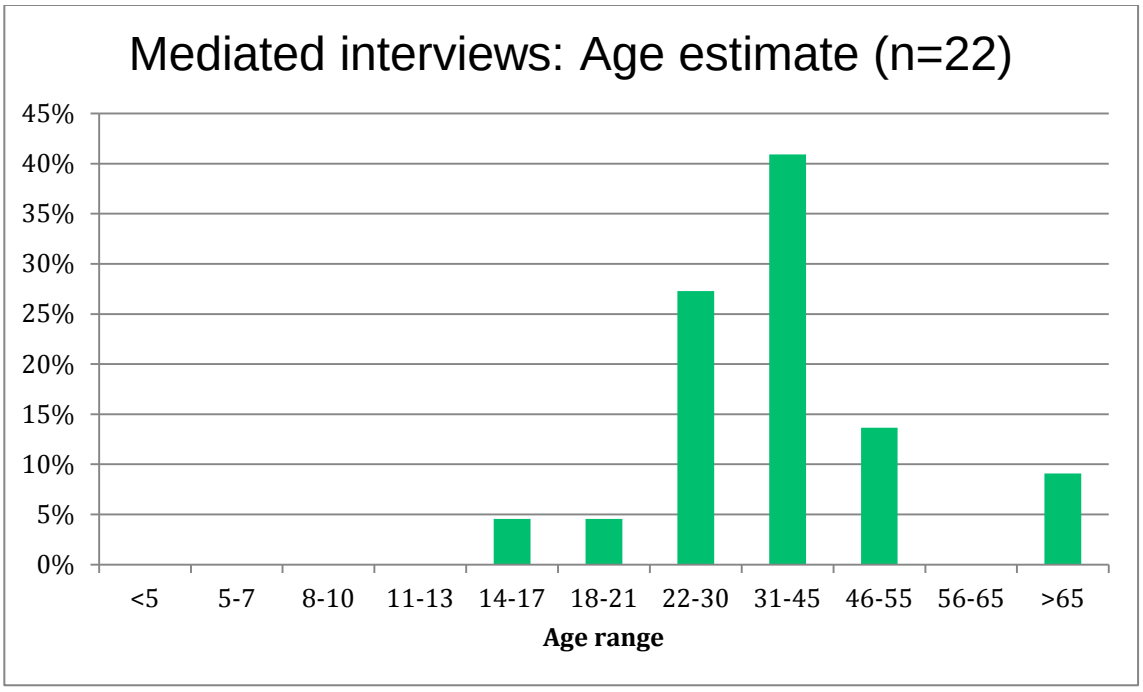
Naturalistic Observations (n=59)		
Age Range	Female	Male
5-8	4	3
9-12	2	3
13-17	0	1
18-25	5	1
26-30	4	3
31-40	6	10
41-50	4	1
51-60	2	2
61+	3	5



Exit Interviews (n=10)		
Age Range	Female	Male
7-17	0	1
18-39	2	3
40+	1	3



Mediated Interviews (n=22)		
Age Range	Female	Male
7-17	1	0
18-39	11	5
40+	2	3



Overall satisfaction and enjoyment

We asked visitors questions about their overall enjoyment and satisfaction with the exhibit in both mediated and exit interviews. At the conclusion of our mediated interviews, we asked participants about their overall satisfaction with their experience. Most (18 of 20) visitors reported that they were satisfied with their experience. When asked in exit interviews how much they enjoyed their experience, on a scale of 1 to 5 (where '1' = *not at all* and '5' = *to a great extent*) respondents (n=9) rated their experience a '4' or '5.' We heard many additional positive comments in our interviews. For example, when we asked visitors an open-ended question about what words they would use to describe the exhibit, we heard: *cool* (female 18-39); *interesting* (female 40+, male 40+); and *very engaging* (male 18-39).

Visitors' first impressions of the exhibit were positive. When we asked about them, we heard the following: "I like that there is a lot going on" (female 18-39); "I like it because I am interested in marine life and whales" (female 18-39); and "I like going through this kind of stuff" (female 18-39). When we asked in mediated interviews how satisfied people were with their experience, nine people used the word "satisfied" or "very" or "extremely." Others used terms we interpret as equal to or greater than 'satisfied', such as: "It's good;" "It's great" (2); and "I'm very impressed." Additional sample positive comments included: "It's very helpful, it is interesting to see how they track them" (male 40+); "I'm satisfied, it's good' (female 18-39); "I'm very impressed, it took a lot of work to make this" (female 18-39); "the content is good, it's very informative" (female

18-39); “I think this is great” (male 40+); “extremely… it shows you where not to swim and I have snorkeled in Hawaii” (female 18-39).

Invitation and navigation

Overall, visitors were attracted to this exhibit. Ninety percent of 22 visitors in mediated interviews said that they would have been attracted to use the exhibit even if we had not asked them to. In exit interviews, two visitors reported being attracted to the exhibit because they like fish and animals. Three were attracted because they like the map and graphics. Five reported that they came up because they like the interactive and movement aspects, and five “because it’s colorful.” When we asked in mediated interviews what their first impression of Mapping Migrations was – before they started using the exhibit – they mentioned a range of first impressions: six visitors mentioned the interactive aspect of the exhibit; eight people mentioned the visual or graphic nature of the table; and twelve people commented about the content and what the exhibit is about.

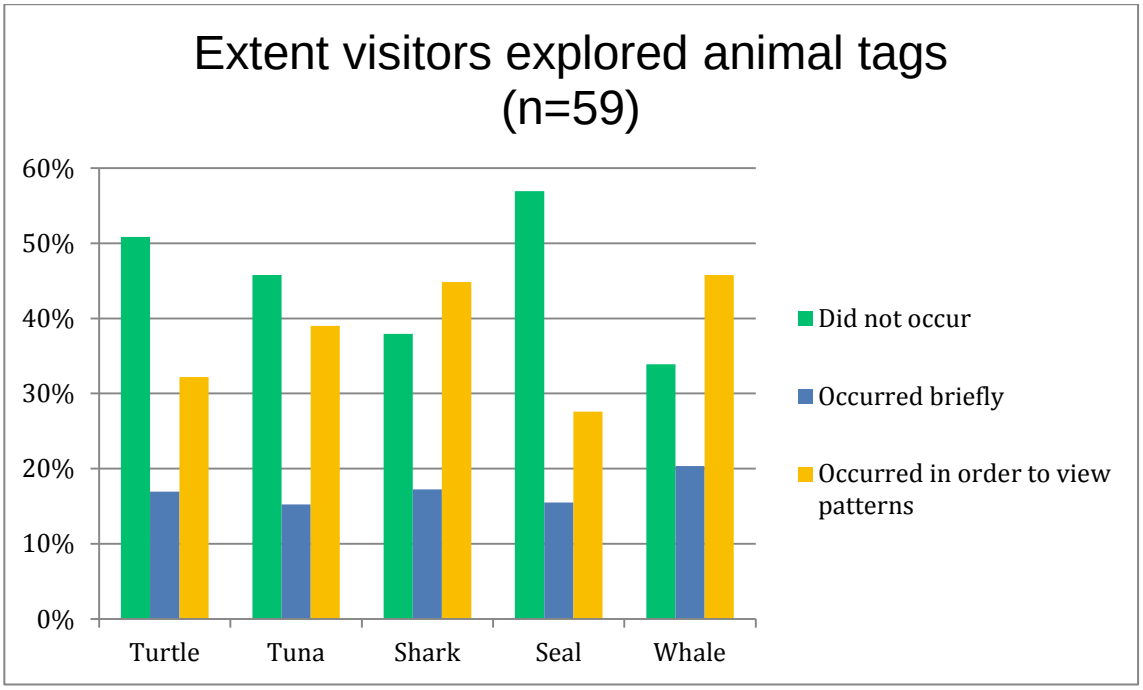
During our naturalistic observations, visitors stayed for a mean of 97.9 seconds (1.63 minutes). The range was from a low of two seconds, to a high of 282 seconds (4.7 minutes). For the most part, visitors were able to navigate the exhibit on a basic level, in the sense that they could determine simply by looking at the table that it displayed patterns of movement for some animal(s).

At the bottom of the table there are five panels (or tabs), one for each of five Pacific predators: tuna, green turtle, white shark, elephant seal, and blue whale. When a visitor taps on a panel or tab, it pops up and displays information on and poses questions about that particular species. There are also two buttons on each panel or tab – one that activates tracking of the species by gender and one that shows where the tagging sites are for each species. Many visitors clicked on one or more of the tabs representing different species, while others did not explore the species tabs at all (in the latter cases, they would be left to observe whatever data the previous visitor had left on the table’s screen). In our naturalistic observations, we wanted to document to the extent possible how often visitors clicked on these tabs in a naturalistic setting, and to what extent they seemed to be reading the information and connecting it to the visualization of the species’ migratory patterns. We coded the visitors’ usage of the tabs as follows:

- a “1” meant that it did not occur at all, that they did not click on or open the tab
- a “2” meant that they opened it briefly but did not seem to read the information on the panel or explore that species’ migratory pattern
- a “3” meant that the visitor used the tab and connected that information with the species’ migratory patterns

Although this measurement of usage is rough, since we cannot be certain whether visitors read a small portion of information, we feel confident that the data presented shows the general pattern of visitors' use of the tabs.

Extent to which visitors used the species tabs	1 (did not occur)	2 (occurred briefly)	3 (occurred in order to observe patterns)
Turtle	30	10	19
Tuna	27	9	23
Shark	22	10	26
Seal	33	9	16
Whale	20	12	27



More often than not, visitors either did not use the species tabs OR they used them in order to observe the patterns. Less often did visitors click briefly on the species tabs.

During navigation, some visitors wanted to be able to manipulate the timeline (by either pausing it or scrolling it forward and backward in time) as they felt this would enable them investigate more of their own questions, using the data. We heard that some visitors would like to pause the timeline at various increments to compare locations for all of the species at particular moments in time (which was too difficult to see with the timeline constantly moving). For example, where are all of the different species in spring? Where are all of the different species in December? We also heard that visitors wanted to be able to pinch-zoom on a particular area or region, in much the same way as one can on an iPad. Sample comments heard during our mediated interviews included: "It would be cool if we could swipe the timeline-there is no pinch zoom, which

I expected. Waiting for the timeline takes too long" (male 18-39); "The timeline is so slow you can't confirm your answer" (male 18-39); "If you could control the timeline, it would be good" (female 18-39); "The timeline goes fast - to stop it would be good" (female 18-39); "I wish you could pause [the timeline] - it moves fast" (female 22-30); "I wish it could stop so you could just watch spring or something" (female 22-30).

In 59 naturalistic observations, we counted how many people read the exhibit questions in the right panel out loud, or where we could observe very obviously that they read the questions to themselves. We documented one person for each of the three questions there.

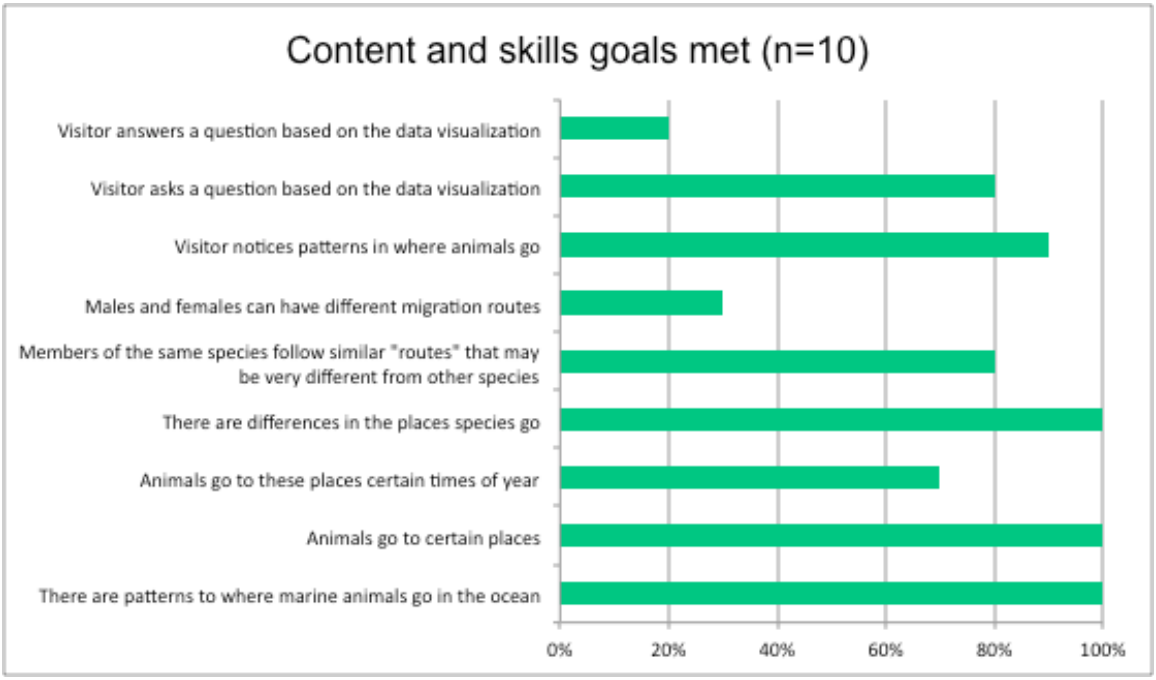
We also noticed during our observations that the table is multi-user friendly, which meant that different visitors could simultaneously use the exhibit. At times, however, this meant that one visitors' investigation might overlap or interfere with another's.

Only once did we observe any technical issues with the table and that was when it froze for about 15 minutes. An Exploratorium Explainer was able to restart the exhibit.

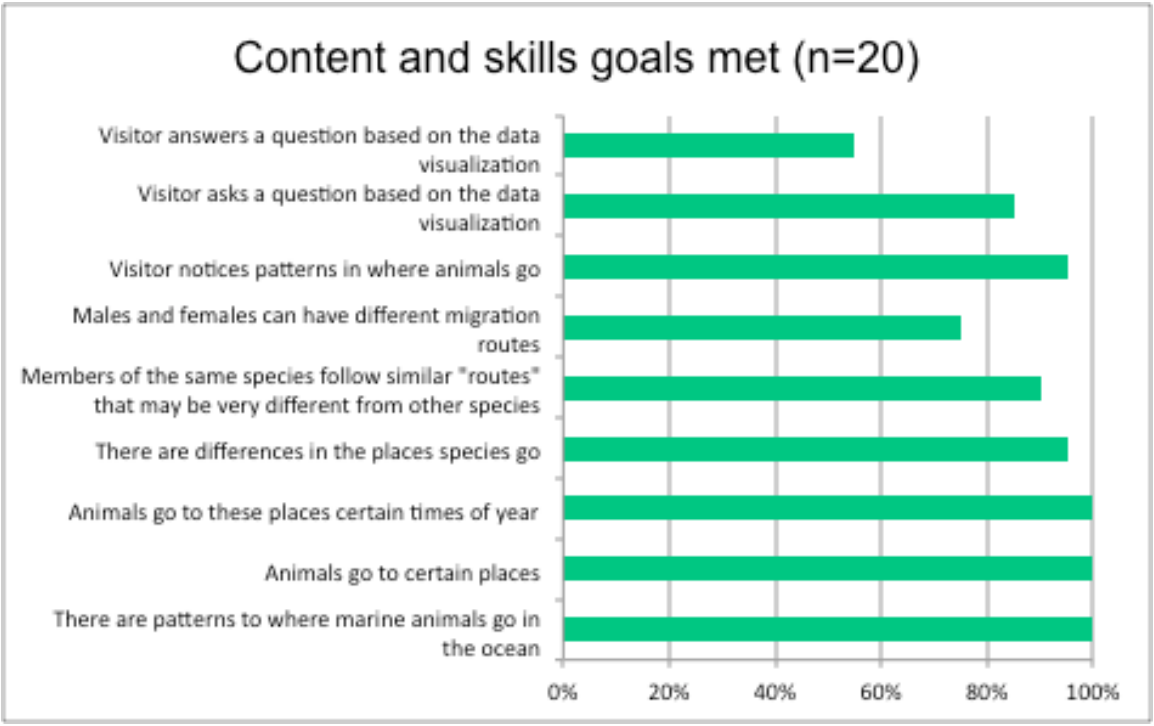
Inquiry and visitors' questions

As noted earlier in this report, the Mapping Migrations project leaders had content and skills goals for visitors who interact with this exhibit. The skills goals included: Visitors will notice patterns in where animals go; Visitors will ask a question based on the data visualization (i.e. "Do the tuna go to the same place turtles do?"); and Visitors will answer a question based on the data visualization.

Exit interviews



Mediated interviews



Visitors asked a range of questions during and after their experience with the exhibit – some of which they could answer and some of which they could not answer (based on the data visualization). In exit and mediated interviews, we heard the following *kinds* of questions, organized by topic.

- The exhibit itself: Using the timeline, species tabs, migration indicators.

In this category, visitors asked questions such as: "can I have more information about how to use the tabs?"; "what is this?" [tapping on the Legend]; "is each dot or dash a point in time, like an hour?" (mediated, male 40+); "is that migration line one animal or a pod?"; and "how many animals does each track represent?" (exit, male 18-39). We noted that several visitors were confused whether the tracks on the screen represented a single animal or a group of animals, which implied that they hadn't read the information located on the sides of the table (where it explains that each track represents one animal). Those questions were answerable using the exhibit.

- Migration: Specific questions about animals in the Pacific and in other regions.

In this category, visitors asked questions such as: "where do sharks go in Winter?"; "do sharks go past Hawaii? Let's find out…What are they doing in the middle of the ocean, and what happened to this guy?" (mediated, female 18-39); "how long does it take for the seals to go north?" (mediated, female 7-17); "why does that one turtle go all the way across?" (mediated, female 18-39); "why do males and females not travel together?" (mediated, female 18-39); "what do animals do south of the Equator?" (mediated, female 18-39); and "there must be equal stuff going on in the Atlantic?" (mediated, male 40+). Typically, these kinds of questions were prompted or sparked by visitors' use of the exhibit but not directly answerable by using the exhibit; however, they would serve well as questions visitors could investigate after their exhibit experience (elsewhere in the museum, at home, etc.)

- Biology of the featured species: What do they eat, why do they do what they do, what kind of animals are they

In this category, visitors asked questions such as: "why does the whale in the picture look so skinny?" (mediated, female 40+); "how do they figure out if the animals are male or female?" (mediated, 13 year-old girl with female 18-39); "why do seals eat in the middle of the ocean? They seem like shore creatures" (mediated, male 18-39); "are these white sharks or great white sharks?" (mediated, female 40+); "how do species relate to each other? Do sharks eat the tuna? Why were they engaging?" (exit, male 18-39); "why did the sea turtle go to Sea of Japan and what was the attraction to go so far?" (exit, male 40+); "why are tuna around California and Baja?" (exit, female 18-39); and "is there anything on the other coast? Are the whales extinct near Asia or is it just that we haven't tagged them there?" (exit, male 40+). Again, these sorts of questions were

prompted or sparked by visitors' use of the exhibit but not directly answerable by using the exhibit; however, they would serve well as questions visitors could investigate after their exhibit experience.

- Science and technology related to the data set: particularly details about how the animals are tracked.

In this category, visitors asked questions such as: "I wonder about tuna tagging and white shark tagging – and how that works" (exit, male 18-39); "are these different years all combined into one picture? Is it looping? Were they all tagged in the same year? For how long do they collect this data? Would we see different tracks if the animals were tagged in different places?" (exit, male 18-39); "how do the tags work? Do they use satellite?" (mediated, female 7-17); "what year is this data from? Is it all from one year?" (mediated, male 18-39); "why do they tag them?" (mediated, female 18-39); and "how do they put the trackers on the animals?" (mediated, 18-39). The answers to some of these questions are explained in the panels on the sides of the table but some are not, and we noted that additional information about the research study(ies) itself would be interesting to some visitors – four of eight said as much. However, during naturalistic observations, we saw only one visitor clearly and obviously read the left panel where the research project is discussed.

In summary, many visitors met the first two goals – noticing patterns and asking questions based on the data visualization – however we did not see visitors answering their own questions using the data visualization, though some could have, had they noticed the panels on the sides of the table.

Conceptual understanding

All visitors we spoke with in exit and mediated interviews understood that the exhibit revealed animal migrations. Following are examples of what exit interview participants reported learning: "I didn't realize tuna were on the California and Baja coasts" (female 18-39); "tuna and seals go much farther than I knew" (female 40+); "animals have a tremendous range. But they don't move as purposefully as I would have thought (male 18-39)"; "I was surprised to see animals in the middle of the ocean (male 18-39)"; "I noticed especially about the blue fin tuna that didn't have the same migration as sharks. Seals were more in the middle of the ocean" (female 18-39); "You can see a lot of whales in the fall. Sharks like Hawaii" (female 18-39); "I would think they would go everywhere! Birds go north and south – is there no place for them to land?" (male 40+); "California has everything. In January to March it's concentrated, then goes to Indonesia" (male 40+); "I noticed that white sharks go to the same places elephant seals go" (male 7-17); "I noticed that sometimes smaller animals travel farther" (male 40+).

Given the above observations, we can report that all visitors met five of the six content goals for this exhibit. Recall that the content goals for Mapping Migrations were:

- Visitors will notice there are patterns to where marine animals go in the ocean.
- Visitors will notice animals go to certain places.
- Visitors will notice animals go to these places certain times of year.
- Visitors will notice there are differences in the places species go.
- Visitors will notice members of the same species follow similar "routes" that may be very different from other species.
- Visitors will notice that males and females can have different migration routes.

It was only this last goal – regarding the different migration routes taken by males and females – that not all visitors met, since not all visitors clicked on the button that displayed the routes by gender or read the key, which explained that the different patterned tracks indicated differences in gender.

Personal relevance and interest in ocean environments and marine life

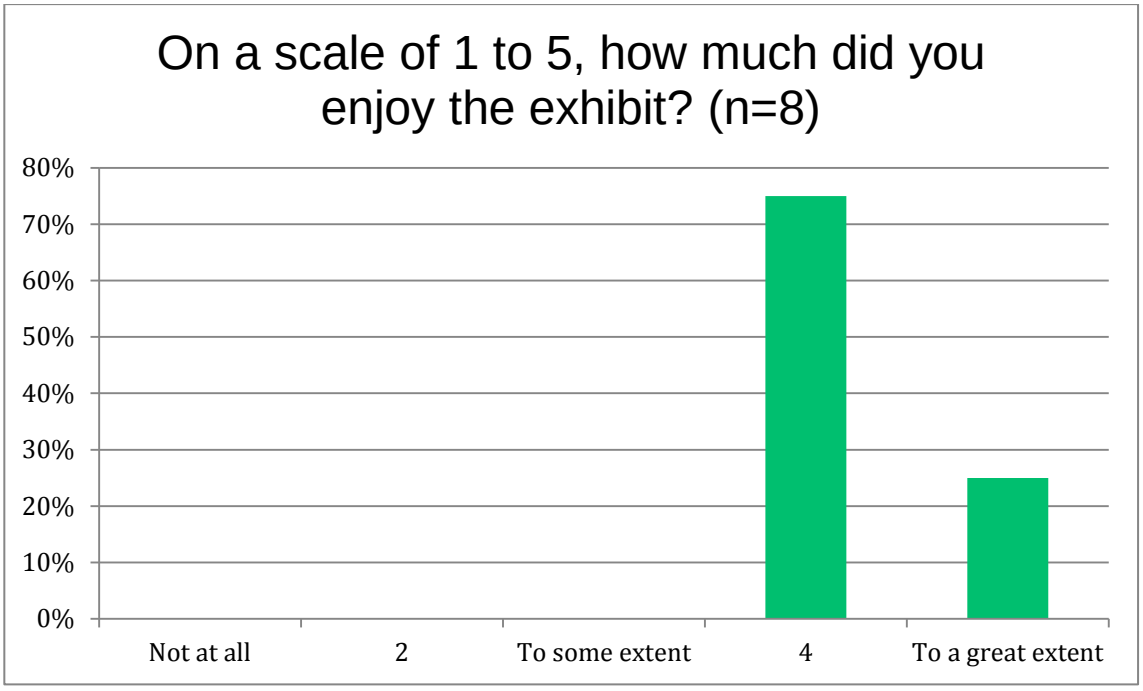
There was evidence that this exhibit had personal relevance for some visitors, where they connected some experience or knowledge in their own life to the places or animals shown in the exhibit. The following responses from exit interviews provide some examples of how visitors related the exhibit to their own lives: “we are going to Hawaii” (female 18-39); “I used to build boats” (male 18-39); “I've done ocean fishing. I knew fish were around but didn't know everything else was” (male 40+); “I saw a tuna, and a white shark at Monterey Bay Aquarium” (male 7-17). In addition, two people mentioned that they have seen television shows about tagging of animals, and two others compared the Mapping Migrations exhibit to an exhibit they had seen at the Tech Museum of Innovation in San Jose.

There seemed to be some, though limited, positive effect on visitors’ interest in the topic of the exhibit. When asked in exit interviews to what extent did spending time at the exhibit influence their interest in ocean environments or marine life,[1] 37.5% (of eight) gave a rating of ‘4’ on a scale from ‘1’ to ‘5’ and 50% said it “somewhat” influenced their interest. We speculate that these numbers are relatively low in part because people approaching this exhibit may have already had at least some interest in the ocean and marine life (one visitor specifically noted, “I’m already interested”).

Summary of Findings

Overall, we found that visitors were drawn to the exhibit, found it interesting, and enjoyed using it. The chart below shows data from exit interviews.

[1] This question was in the form of a rating scale, where ‘1’ = *not at all*, and ‘5’ = *to a great extent*.



Visitors were able to navigate the exhibit to their satisfaction; however, most visitors did not access the information located in the panels on the sides of the exhibit and therefore were not always aware of what they missed. In addition, a few people mentioned wanting to manipulate the timeline in order to further investigate their questions about the timing of the various migrations. Topics of particular interest were the long-range migrations of tuna and turtles; the habits and locations of white sharks; and to a lesser extent, interest in how the research was conducted and how the animals were tagged. We heard what we consider to be fruitful or generative conversations, where comments such as "I wonder if…" and "oh wow look at that!" indicated that visitors were engaged with the exhibit and each other, and might have been prompted to continue their inquiry after leaving the exhibit.

With respect to the content and skill goals set forth by the Mapping Migrations project leaders, the exhibit was largely successful. All visitors noticed there are patterns to where marine animals go in the ocean, they noticed marine animals go to particular places at particular times of year, and that these patterns vary by species. Some, though not all, visitors noticed that males and females can have different migration routes. Many visitors asked questions based on the data visualization and some were able to answer their questions using the data visualization. Where visitors did not answer their questions using the exhibit, it was either because they hadn't read the panels on the sides of the table or because the exhibit did not provide an answer. It is fortunate that the exhibit prompts visitors to ask generative questions that may drive future inquiry.

Living Liquid
Plankton Populations Summative Evaluation Report

Inverness Research
July 2017

Introduction

The Exploratorium, a museum of science, art, and human perception, has partnered with scientists and data visualization specialists to create three exhibits around three separate large data sets that will allow visitors to interact with scientific data on oceans. Inverness Research is responsible for studying the nature and quality of the partnerships and network created by this project, and for conducting a summative evaluation of the exhibits and the project as a whole. As stated in the project's proposal to NSF, Inverness seeks answers to the following key evaluation questions:

- What is the nature and quality of the partnerships between informal science educators, computer scientists, and research scientists? What are the important lessons learned from this partnership and network that could inform the broader field of informal science education and broader outreach efforts of scientists?
- What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships? In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data? What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?

Inverness has been contracted to provide summative evaluation on three Living Liquid visualizations: Plankton Populations (PP), Mapping Migrations (originally known as Tracking of Pacific Predators, TOPP), and Sea of Genes (also known as Metagenomics). This document summarizes the data collected for the summative evaluation of the first – the Plankton Populations – visualization. (Inverness also conducted update calls with project leaders and interviews with Living Liquid partners. Those activities are not included in this summary.)

Evaluation approach and data sources

The outcomes for visitors, originally identified for these exhibits in the project proposal, are as follows:

- Visitors are interested in the topic of ocean environments and marine life
- Visitors pose productive questions answerable with the database
- Visitors answer their questions by using the visualization to look at the data

- Visitors look at different variables and relationships
- Visitors interpret the data to identify patterns in marine life and environmental factors
- Visitors understand the connections between marine life and their environment
- Visitors have an awareness that scientists study oceans by collecting and analyzing data

Desirable outcomes that the Exploratorium's Living Liquid team had identified just prior to summative evaluation:

Content

- Visitors will make an observation based on the data (number of plankton, how change over time, location, etc.)
- Visitors will notice that there is microscopic life in the ocean
- Visitors will notice that this microscopic life varies in the ocean (by time, by location, by amount - any change)
- Visitors will observe that the microscopic life changes depending on the environmental conditions

Skills

- Visitors will make an observation based on the data
- Visitors will make comparisons (geographic, location, variables changing) - can be with one lens or two
- Visitors will ask a question based on the data
- Visitors will attempt to answer a question

Inverness used three methods to gather data related to the above goals for the Plankton Populations exhibit, collecting more data than was originally planned in the project proposal.

Naturalistic observations of 59 visitors interacting with the exhibits. We documented the time visitors spent at the table, the nature of their interactions with the exhibit, and the conversations visitors had with others they were interacting with while using the exhibit. (See Appendix A for naturalistic observation protocol.)

Exit interviews with 11 visitors after they used the exhibit. We conducted exit interviews with a subset of visitors we naturalistically observed in order to better understand their engagement with the exhibit, their conceptual understandings, and any further questions they were interested in pursuing. (See Appendix B for visitor interview protocol.) Initially, our plan had been to conduct exit interviews with a greater number of those individuals we observed naturalistically; however, because the dwell times of those we observed was so low, we decided to put additional effort into mediated interviews, in order to better understand visitors' experiences and understandings.

Mediated (think aloud) interviews with 21 visitors during their interactions with the exhibits. We conducted interviews with visitors as they used the exhibits, in order to better understand

the nature of the inquiries visitors make with the data, and the nature of their understandings of the data as they interact with the exhibits. (See Appendix C for mediated interview protocol.)

The same one to two researchers collected data on a series of days in August and October 2017. We varied the day of the week to maximize the number of visitors who would be present during that particular season.

Data Collection		
Day	**Date**	**Season**
Thursday	August 17	Summer
Saturday	August 20	Summer
Wednesday	August 24	Summer
Saturday	October 8	Fall
Sunday	October 16	Fall

Findings

Naturalistic Observations

Our naturalistic observation protocol provided space for the observer to make note of situations in which visitors engaged in any behavior indicating that content or skills goals might be being met. We looked for evidence that visitors were engaged in particular behaviors, such as using plankton viewers, using tabs on viewers, making observations based on the data, or asking their own questions based on the data. Some of the content and skills goals would not be readily observable (whether a visitors was making comparisons, for example) unless visitors were speaking aloud; therefore, we followed up with a subset of visitors in exit and mediated interviews to investigate some of these more nuanced behaviors.

When conducting our naturalistic observations, we started a timer as soon as visitors approached the table. In addition to documenting the gender and approximate ages of visitors in a group, our protocol (see Appendix A) tracked:

- Whether the visitor moved the plankton viewer (if at all) on the table
- Whether the visitor used the Ocean Conditions tab on the viewers
- Whether the visitor voiced any observations they made based on the data
- Whether the visitor read any of the exhibit's questions (below) aloud
    - Why are there no plankton near the poles at certain times of the year?
    - Which type of plankton thrives where nitrogen is very low?
    - Which types of plankton live along the California coast?
    - Where are there few or no plankton growing?
    - Do different types of plankton thrive near the equator and near the south pole?
    - What is the difference in ocean conditions between areas with green plankton and with purple plankton?

- Whether the visitor asked their own questions aloud based on the data (including whether they proposed an investigation or inquiry)

As noted above, we also attempted to capture whether visitors engaged in the following behaviors; however, given that these are difficult to determine from observation alone, we ultimately probed for these in interviews:

- Whether the visitor used the exhibit to answer their own or the prescribed questions
- Whether the visitor made comparisons (e.g. between geographic and other variables)
- Whether the visitor made connections between the exhibit and their own lives
- Whether the visitor made predictions, offered explanations, or described cause and effect relationships
- Whether the visitor provided alternate explanations or tried an additional exploration
- Any other behaviors
- Comments that visitors made while interacting with the exhibit

During our 59 naturalistic observations, visitors spent a mean of 78 seconds at the Plankton Populations table. The least amount of time visitors spent was four seconds and the most was 320 seconds.

Following is a sample of scenarios we observed at the Plankton Populations exhibit. We believe these to be representative of the types of visitors' behaviors, observations, and comments. They also provide a snapshot of how visitors navigated and made sense of the exhibit and the types of responses the exhibit elicited or conversations it generated.

- A handful of adults approached the table, looked at it, reviewed the questions, and then walked away.
- One adult female commented to her group: "*there's Europe. Not sure what this means. Does this mean that there's only planktons that live in nitrogen and that need silica? Can you rotate this? The world is not flat."*
- One adult female said to the others in her group: *"it shows you how much and where plankton is."*
- An approximately 40-year old woman who was with an adult male, a 9-year old boy, and an 11-year old girl said *"oh, this is interesting."* The adult male asked, *"who eats plankton?"* The boy responded *"whales."* The adult male continued, *"what are they [plankton]? Little fish, I guess."*
- One adult female who was with a girl about four years of age said *"plankton is a little plant that lives in the ocean. Want to see different types?"* She then read the legend with the four types of plankton to the girl. Then she made a connection between the legend and a type of plankton that they saw at another Living Liquid exhibit nearby.
- A boy said to his mother: *"hey mom, look at this… how nitrogen changes and there's no plankton on land... What about on my birthday?*" and watched the timeline.

Overall, we did see visitors using the plankton viewers and less often, clicking on the tabs on the viewers to display the light, nitrogen, and silica patterns. When visitors were in pairs or groups, we heard them voicing observations based on the data. During these naturalistic observations, we did not see much, if any, evidence that the visitors were reading the questions from the exhibit, or asking their own questions based on the data. The frequency of these behaviors and more were explored during our interviews with visitors.

Exit interviews

After observing visitors interact naturally with the Plankton Populations exhibit, we determined that two minutes seemed a reasonable amount of time to pass before visitors would begin to notice patterns in the plankton populations and make connections between plankton populations and variables such as nitrogen and silica. If visitors stayed at the table for two minutes or more, we asked whether they would be willing to be interviewed. There were a total of 15 such visitors, some of whom did not speak English, resulting in 11 "exit" interviews. We assume that they are representative of other visitors who stayed for two minutes, with the exception of language differences. We spoke with five females and six males (these visitors did not identify as any gender other than male or female). The females were aged nine, 12, 30, 40, and 40; the males were aged nine, nine, 10, 25, 45, and 60.

Exit interviewees		
Age range	Female	Male
9-12	2	3
25-30	1	1
40-45	2	1
60+		1

Our exit interview protocol (see Appendix B) covered the following topics:

- What the visitor thought the exhibit was about
- Whether the visitor learned anything new from the exhibit
- The extent to which the visitor enjoyed the exhibit
- The extent to which the visitor is interested in the topic of ocean environments and marine life
- The extent to which spending time at this exhibit influenced the visitor's interest in ocean environments or marine life
- What, if anything, the visitor observed about the different variables present in the exhibit
- Where the visitor thinks that the data for the visualization came from
- Whether the visitor attempted to address any of the questions that the exhibit suggested
- Whether the visitor asked any of their own questions while at the exhibit

- ❖ Whether the visitor made any connections between this exhibit and their own life
- ❖ What words they would use to describe the exhibit

The following sections provide a sample of visitors' responses during exit interviews, according to age.

What the visitor thought the exhibit was about
In general, most visitors quickly discerned that the exhibit was about plankton in different parts of the world.

A boy about nine years old said:
It shows different plankton in different colored areas. In most areas they are green, with very low nitrogen levels. These are all the plankton in all the months.

A girl about nine years old said:
You take these things [the viewers] and you'll see the different types of purple and flower things… blue - not sure what it is. Tabs show different things about them. Show you what color you had to go on to see what they are (purple water shows purple plankton).

A nine-year old boy said:
Plankton is different in different places, green plankton is tiny, blue plankton has tails. They look like brains with tails, purple is spine-y.

A boy about 10 years old said:
When plankton is in different parts of the world.

A 12-year old girl said:
Ocean life and plankton. Plankton varies by month and temperature.

Adults had very similar responses to the children's.

A 30-year old woman said:
The plankton, where they are and aren't in the ocean.

A woman about 40 said:
Plankton populations in different areas of the ocean.

A woman in her 40s said:
There are four different types of plankton and they change by regions

The older adults' responses were similar, though they took them a step beyond what was apparent on the table.

A 45-year old man said:
The flow of nutrients around the ocean. What creatures are appearing and inviting other larger animals that eat them; would be migrating and moving.

A man about 60 said:
Life in the ocean and how it changes through the seasons.

Whether the visitor learned anything new from the exhibit
In general, visitors learned specific details about plankton that they didn't know before.

A nine-year old girl who was present with her mother said:
I learned about different types of animals in areas. I didn't know there's different types of colors in the ocean.

A nine-year old boy said:
A lot of plankton look like cells.

A 10-year old boy said:
There was a lot about plankton I didn't know about… that plankton moves to get to places.

A 12-year old girl said:
How much plankton there really is, and how much there is in certain months in certain areas.

A man about 25 years old said:
I don't know much about plankton. I learned that it's pretty much everywhere; I thought it was only in remote areas.

When we asked one woman about 30 whether she learned anything from the exhibit, she said:
No, I had a hard time trying to figure it out.

A man about 45 said:
I learned a bit - I don't have these [names] memorized like he [son] does. So there are four categories [of plankton] and three key components [Ocean Conditions] and how they rely on them and how it shifts in different bands… there is a shift in mix at different times of year, especially the light.

A 60-year old man, when asked whether he had learned anything new from the exhibit, said, *"not yet. It's still more of a game."*

RATING SCALES

We asked visitors a series of questions and asked them to provide an answer in the form of a rating, on a scale from one to five (with one meaning "not at all" to five meaning "to a very

great extent"). Note that the sample size for these ratings is so small that one should use caution in deriving too much meaning from them.

First we asked them to rate the extent to which they enjoyed the exhibit. Visitors provided an average rating of 3.94, close to 4, with a range from 2 to 5.

We also asked visitors to rate how interested they were in the topic of ocean environments and marine life. Visitors provided an average rating of 4, with a range from 2 to 5.

Finally, we asked visitors to rate the extent to which spending time at this exhibit influenced their interest in ocean environments or marine life. Visitors provided an average rating of 3.7 with a range from 3 to 5.

What, if anything, the visitor observed about the different variables present in the exhibit

This exhibit involves a number of different variables including: geographic variables (i.e. locations on the planet); variables inherent to the plankton themselves (e.g. plankton type and amount); temporal variables (e.g. month of the year); and environmental variables (e.g. levels of Nitrogen, Light, Silica). All visitors quickly understood that the table displayed a map of the planet Earth, with different types and amounts of plankton located in different areas. Some visitors noted that they expected the land to be green and the oceans to be blue as they are on many standard maps. Also, some visitors wanted to see major cities labeled on the maps, so they could orient themselves more quickly. Nearly all visitors noticed the chronological aspect of the exhibit, in the sense that they noticed the calendar scrolling at the top of the table. However, some visitors were not clear whether it was the same year repeating over and over, whether it was a series of years in succession, and/or whether it was the same calendar year for all of the different types of plankton at once.

Many visitors did not notice the tabs for select environmental variables and when they did, the calendar seemed to scroll too quickly for them to match up how the variable matched with the plankton populations. When asked about what they observed about the different environmental variables addressed in the exhibit, two visitors said they hadn't looked at the variables. One nine-year old boy said he noticed that the three viewers corresponded with three different conditions (which is not entirely accurate). He also said he had been exploring nitrogen levels in different areas. Another visitor said he noticed that the amount of plankton varies by month and temperature, but did not notice the different tabs on the viewer.

Where the visitor thinks that the data for the visualization came from

No one we spoke with during exit interviews knew where the data for the exhibit came from.

Whether the visitor attempted to address any of the questions that the exhibit suggested
A nine-year old boy attempted to address the questions suggested in the exhibit. A ten-year old boy said:
No. I didn't know that the land was land. It didn't say the names of the plankton.

A 45-year old man described preferring to follow his own path through the exhibit:
No. I was mostly doing my own thing; curiosity governing where I move.

Whether the visitor asked any of their own questions while at the exhibit
Two visitors asked their own questions while at the exhibit:

A 40-year old woman who was with three others mentioned that they are from Hawaii so they were interested in where whales might go for plankton:
Where would whales go to eat plankton? Checked out areas where they would go.

A nine-year old boy asked:
Would most plankton be where there's most nitrogen?

Whether the visitor made connections between the exhibit and their own lives
The most obvious connection visitors made between the exhibit and their own lives was for the visitor group from Hawaii, who focused on plankton with respect to whales and where whales might go to find plankton.

Words visitors used to describe the exhibit
Words visitors used to describe the exhibit included: *interactive*, *depth*, *visual*, *cool*, *amazing*, and *awesome*.

Other comments
One adult male visitor suggested having a tab that showed what animals feed on the plankton, and to represent some zooplankton. One nine-year old boy said that he loved the surface and "every time I see a screen, I get sucked in!" He suggested that a visitor should be able to increase or decrease the field of vision (similar to an iPad). A mother suggested adding an audio component to guide visitors through the exhibit.

Mediated/think-aloud interviews

After completing our naturalistic observations and exit interviews and analyzing those data, we still felt we didn't fully understand what a visitor might get out of the exhibit, if invited to spend more time with it. We felt there was a threshold of time required for visitors to really make sense of all of the variables at work in the exhibit and so we conducted mediated interviews. We recruited visitors from the museum floor and asked them to spend some time using the Plankton Populations exhibit and to think aloud with us. Our protocol (see Appendix C) asked for basic background information from the visitor such as: their approximate age, gender, how

often they come to the Exploratorium, whether they were a member at the time of data collection, how long they had been at the museum that day, whether they had used this particular Plankton Populations exhibit before, and whether they interacted with any of the other exhibits in the Living Liquid exhibition. The protocol was divided into four elements: context of invitation, navigation, nature of inquiry, and conceptual understanding. The protocol also indicated the desired content and skill outcomes that the Exploratorium had identified for this exhibit.

We conducted mediated interviews with 21 visitors; 12 males and nine females (these visitors did not identify with any gender other than male or female). Eight visitors (four females and four males) were between the ages of seven and 17, eight (three females and five males) were between the ages of 18 and 39, and five (two females and three males) were 40 or older.

Mediated interviewees		
Age range	Female	Male
7-17	4	4
18-39	3	5
40+	2	3

First impressions/invitation

Some visitors thought the exhibit surface was a touch screen and they were drawn in by the colorful nature of the display. All visitors deduced that the exhibit was about plankton populations around the world (given the title).

> *It's looking at different plankton populations, by region, through time on an interactive map.*
>
> *About plankton – maybe where it is and the month.*
>
> *Plankton populations for the year?*

Three visitors mentioned needing to take a moment to orient themselves to the map. Some thought the colors indicated temperature of the water. One visitor was used to seeing black as an indication of water and color as an indication of land whereas in this exhibit it is the opposite. Three visitors said they were confused about what to do when they first approached the table and suggested prompts such as "try this" or "play with this" as a means to get visitors started. Three visitors said there was a lot of text and they were unlikely to read it. One used the word "intimidating" in describing the text.

Only four visitors said they would not have been attracted to the exhibit if we hadn't asked them to interact with it. One said "no, it looked like too much work" and one said "no, there's too much text." Another said "no, I'm not drawn to touchscreens." The remaining visitors said they would have been attracted to the exhibit because it is colorful and interactive, though they

added that they wouldn't have looked at it as thoroughly or learned as much if we hadn't asked them to try it.

In summary, for the Context of Invitation element of the evaluation we found that:

- because of the name of the exhibit, and the universal familiarity with maps of the Earth, visitors were able to identify "what the exhibit is about" before using it.
- the table top is attractive to children as they think it is a touch pad.
- the amount of text is a barrier for some visitors.

Navigation

We asked visitors to start using Plankton Populations and to "think aloud" about what surprised them, what questions they had, and whether they made any observations based on the exhibit. It took a while for four different visitors to notice that the Ocean Conditions tab popped out to reveal Nitrogen, Light, and Silica levels.

> *I didn't know the Ocean Conditions tabs happened.*
>
> *Oh wow, this [Ocean Conditions] tab pops out.*
>
> *Whoa! I didn't realize these [Ocean Conditions] popped out.*

We observed visitors placing their fingers on the lenses/viewers and trying to expand them or shrink them, as you would on a touchscreen. Similarly, we saw visitors double click on things they wanted to enlarge (the viewers) or pause (the timeline). Four mentioned that they would like to be able to manipulate the timeline in different ways – pause it, slow it down, fast forward it into the future, etc.

> *I can't pause the timeline or go into the future.*
>
> *I don't know what the timeline is for. I want to pause it or manipulate it.*
>
> *The timeline – I can't pause it or change it. Can't manipulate it. It goes too fast, I can't slow it down.*

One visitor simply didn't understand the timeline. It took some time for two other visitors to notice that the timeline moved automatically and that the timeline on the bottom of the exhibit aligned with those in the Ocean Conditions tabs. One visitor noticed that there is no scale or units of measurement on the graphs in the Ocean Conditions tabs.

In summary, for the Navigation element of the evaluation we found that:

- all visitors were able to use the viewers and move them around.
- not all visitors figured out the ocean conditions tabs on the lenses/viewers.

- visitors expected and wanted to be able to influence or control the timeline at the bottom of the panel.
- many people didn't see the questions at the bottom of the panel because they were leaning over them as they used the table top.
- when there were a lot of visitors around the table, sometimes people tried to move their viewers on top of the viewers of other visitors.

Nature of inquiry

Data collection on the nature and frequency of visitors' questions surfaced some challenges for the Inverness team; these challenged were noted by the project team as well. Visitors might not define a "question" in similar ways. For some, a proposal for investigation such as "let's see what happens in the Arctic" would qualify as a question but for others, it may not. Also, when asked about what questions they have, some visitors may overlook the questions they've already answered and focus only on those that remain unanswered. This is a limitation that should be addressed in future data collection efforts.

In response to our question "what questions do you have now that you have spent time with the exhibit?" some visitors responded by asking questions about the exhibit itself and some responded by asking questions associated with plankton. One visitor said they didn't know enough to have a question. One said they wondered who "dined on" the plankton. One asked whether there were other types of plankton or just these four.

One visitor did not ask many questions in this section but did ask many questions during her initial exploration of the exhibit, such as: "Does this timeline [in viewer] align with this [lower table] one? Why is this area all black? Nothing in the legend is black. I do see some purple guys. [Later she answered this question when she read: 'where are there few or no plankton growing?'] I'm wondering why, on a broader scale, how does their population relate to other factors, the bigger picture? Is there anything to do with temperature? Why do these [ocean conditions] flat-line? When closer to the equator they don't need as much nitrogen? It looks like there's a lot of blue and green [species]. One needs lots of nitrogen and one doesn't; I'm wondering why. The light levels never got low while the nitrogen levels can. How low is low?"

Four visitors said they didn't have any questions. Three visitors said they wanted to know more about how climate change interacts with plankton populations and how the populations might change over the long term, from 100 years from now to different millennia. The majority of visitors were not able to explore their own questions with the exhibit as it stands, since it didn't include: information on food webs, background information on plankton (e.g. what they eat, what eats them); the range of plankton that exist (e.g. are there only four types or are there more?); data from periods of time longer than one year; or how plankton populations might be relevant to climate change.

In summary, for the Nature of Inquiry element of the evaluation we found that:

- these visitors asked the most questions when they were simply getting to know and exploring the exhibit.
- some visitors were interested in plankton more broadly, such as how many types of plankton there are and where they fit in the food web.
- several visitors were interested in the relationship between plankton and climate change and how plankton populations might be an indicator of, or change as a result of climate change.
- most visitors were unable to answer the questions they posed themselves with information from the exhibit.

Conceptual understanding

Perhaps because of the structure of our protocol and/or the wording of this question, visitors did not say much to indicate the conceptual understanding they developed while using the exhibit. They did understand that plankton is microscopic life in the ocean and that plankton varied by amount, time, and geography. While some visitors noticed that nitrogen, light, and silica were highlighted as environmental variables, they did not mention *how* or *why* these variables are related to plankton populations. A few visitors mentioned the relationship between temperature and plankton but since the exhibit did not explicitly mention temperature, this seems to be more of a hypothesis or a misconception among visitors, rather than something they came to understand as a result of the exhibit. In addition, because the legend does not refer to anything black and because on the tabletop, black is the color of the land, some visitors were confused about what the black in the ocean near the poles indicated.

In summary, for the Conceptual Understanding element of the exhibit we found that:

- visitors were able to describe the exhibit as one about different kinds of plankton around the world.
- visitors noticed that there is microscopic life in the ocean.
- visitors noticed that this microscopic life varies in the ocean (by time and by location).
- not many people explored the ocean conditions part of the exhibit in any detail.
- as visitors explored in the mediated interview context, some had quite a few questions; they wondered aloud quite a bit. They didn't seem to mind that there were not always answers to those questions, and it seemed like more of an intellectual exploration.
- there seemed to be some confusion about the black ocean areas around the poles, and what that represents. "The abyss" is a term that a few people mentioned to describe those areas.
- not surprisingly, visitors with science training, data analysis, or engineering backgrounds, were more quickly able to navigate the exhibit and articulate the basic concepts presented (and ask more in-depth questions).

Inverness Research Summary and Reflections

Visitors spent an average of 78 seconds at the Plankton Populations exhibit, with a range from four to 320 seconds. Those who stayed close to a minute or longer – about half – used the viewers and were able to determine that the amount of plankton varies by location, time, and other conditions.

The display itself was compelling, though the majority of visitors we interviewed said they would not have read the text surrounding the visual, except for perhaps looking at the legend to see what the colors represented. Unfortunately, the text was not backlit during our data collection, which made it less obvious. With regard to the colors of the exhibit, several visitors liked how colorful and visually appealing the table is; however, some noted it took a while to figure out that the dark spaces on the table represented the continents and the colored areas represented the oceans. Some visitors expected the colors to represent temperature, with blues representing cooler temperatures and pinks representing warmer temperatures.

Visitors sometimes had outsized expectations of the exhibit. Some expected the table itself to be more interactive. We saw visitors trying to interact with it like an iPad or tablet – double clicking on locations, expecting to be able to enlarge or zoom in on areas, pause the timeline, and perhaps be able to *manipulate* the conditions in a certain area (thereby manipulating the data) rather than simply observe the conditions' influence on the plankton. In addition, some visitors wanted to be able to witness change over time for a period greater than one year, address questions related to pollution and climate change, and make predictions into the future. We do not know whether visitors understood this was a visualization of real data (even though the display explains this), much less understood the limitations of observing and interacting with a real data set.

Challenges

The limitations of the data set are an example of a challenge presented by creating an exhibit that is a visualization of actual scientific data. Visualizations can serve a variety of purposes, including as scientific tools, exploratory tools, and explanatory tools. A challenge that faces the ISE field is how to create visualizations that are scientifically accurate and communicate important ideas, while still fostering true inquiry? How can one create an exhibit using visualizations that allows visitors to manipulate variables while maintaining an accurate representation of the data? Visitors' inquiries are necessarily bounded by what is available in the actual data. As one project leader stated:

> *The challenge here is how do you keep the phenomena somewhat pure and foster observation without layering so much content on it that it becomes a website?*

Successes

The exhibit was successful in producing the outcomes that the Exploratorium's Living Liquid team had identified for visitors interacting with the exhibit. Recall that the team listed desirable outcomes in two categories – content and skills:

Content

- Visitors will make an observation based on the data (number of plankton, how change over time, location, etc.)
- Visitors will notice that there is microscopic life in the ocean
- Visitors will notice that this microscopic life varies in the ocean (by time, by location, by amount - any change)
- Visitors will observe that the microscopic life changes depending on the environmental conditions.

Skills

- Visitors will make an observation based on the data
- Visitors will make comparisons (geographic, location, variables changing) - can be with one lens or two
- Visitors will ask a question based on the data
- Visitors will attempt to answer a question

Our evaluation documented visitors: making a range of observations; understanding that plankton are microscopic life in the ocean; observing that plankton varies in the ocean by time and location; and noticing that plankton varies by environmental conditions (e.g. levels of nitrogen, light, and silica). Visitors also compared the relative presence or absence of plankton in different locations, under different environmental conditions, and over time. Most visitors we observed and interviewed also asked questions and attempted to answer those questions using the exhibit. At some times, those questions were not answerable by the exhibit due to the limitations of the data set; however, visitors still made attempts and were engaged in the process.

Living Liquid
Sea of Genes Summative Evaluation Report

Inverness Research
March 2018

Introduction

The Exploratorium, a museum of science, art, and human perception, has partnered with scientists and data visualization specialists to create three exhibits based on three separate large data sets that will allow visitors to interact with scientific data on oceans. Inverness Research is responsible for studying the nature and quality of the partnerships and network created by this project, and for conducting a summative evaluation of the exhibits and the project as a whole. As stated in the project's proposal to NSF, Inverness seeks answers to the following key evaluation questions:

- What is the nature and quality of the partnerships between informal science educators, computer scientists, and research scientists?
- What are the important lessons learned from this partnership and network that could inform the broader field of informal science education and broader outreach efforts of scientists?
- What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships?
- In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data?
- What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?

Inverness has been contracted to provide summative evaluation on three Living Liquid visualizations: Plankton Populations (PP), Mapping Migrations (also known as Tracking of Pacific Predators or TOPP), and Sea of Genes (referred to internally as Metagenomics). This document summarizes the data collected for the summative evaluation of the third – the Sea of Genes – visualization. (Inverness also conducted update calls with project leaders and interviews with Living Liquid partners. Those activities are not included in this summary.)

Background

The anticipated outcomes for visitors to these exhibits were originally identified in the project proposal as:

Engagement, Interest

- Visitors are interested in the topic of ocean environments and marine life

Skills

- Visitors pose productive questions (i.e., answerable with the dataset)
- Visitors answer their questions using the visualization to look at data
- Visitors look at different variables and relationships
- Visitors interpret the data to identify patterns in marine life and environmental factors

Awareness, Knowledge, Understanding

- Visitors understand the connections between marine life and their environment
- Visitors have an awareness that scientists study oceans by collecting and examining data

Evaluation approach and data sources

For Inverness' previous two summative Living Liquid evaluations – of Plankton Populations and Mapping Migrations – we used three methods to gather data: naturalistic observations, exit interviews, and mediated (think aloud) interviews. For the Sea of Genes exhibit, we discovered early that visitors were not spending sufficient time at the exhibit of their own volition, to be able to answer the questions we were interested in addressing in exit interviews. We therefore focused our efforts on naturalistic observations and mediated interviews.

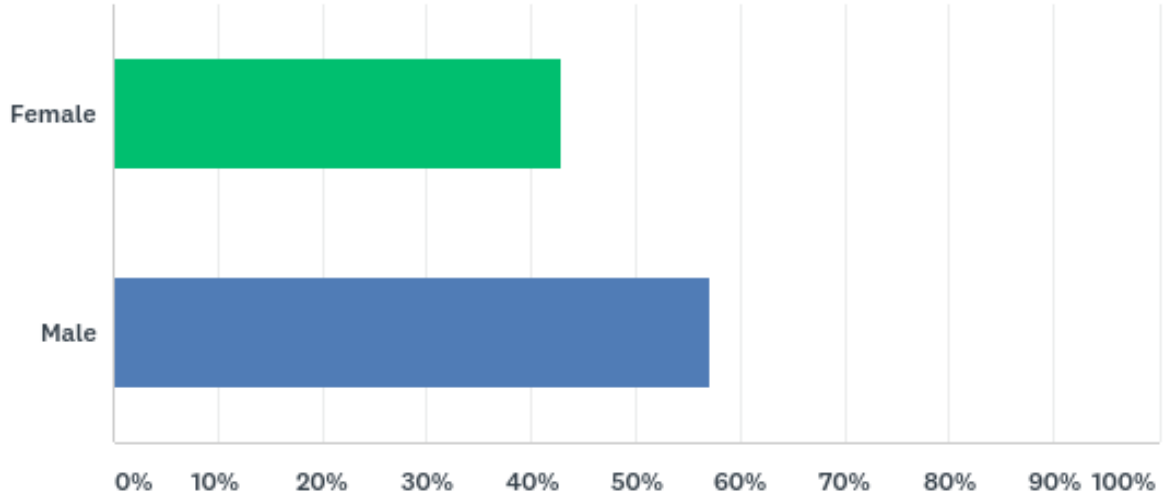
Naturalistic observations. Inverness conducted a total of 56 naturalistic observations: eight on October 15th (along with 13 mediated interviews), 29 on December 10th, and 19 on December 17th. To maximize the amount of data we could collect, we selected visitors for observation simply by choosing the next person who approached the exhibit, after we completed our previous observation. In other words, we observed one visitor (or pair) and when we completed our protocol, we began observing the next visitor (or pair). We documented the time visitors spent at the table, the nature of their interactions with the exhibit (if any), and the conversations visitors had with others as they used the exhibit (if any).

Mediated (think aloud) interviews. We conducted mediated interviews with 13 groups during their interactions with the exhibit. We approached the next visitor (or pair) who was within a radius of ~20 feet of the exhibit, and invited them to talk with us as they used the exhibit. They confirmed verbally that we could talk with them, to better understand the nature of their experience with the exhibit. We tracked the gender of the individual in the group who provided the most feedback.

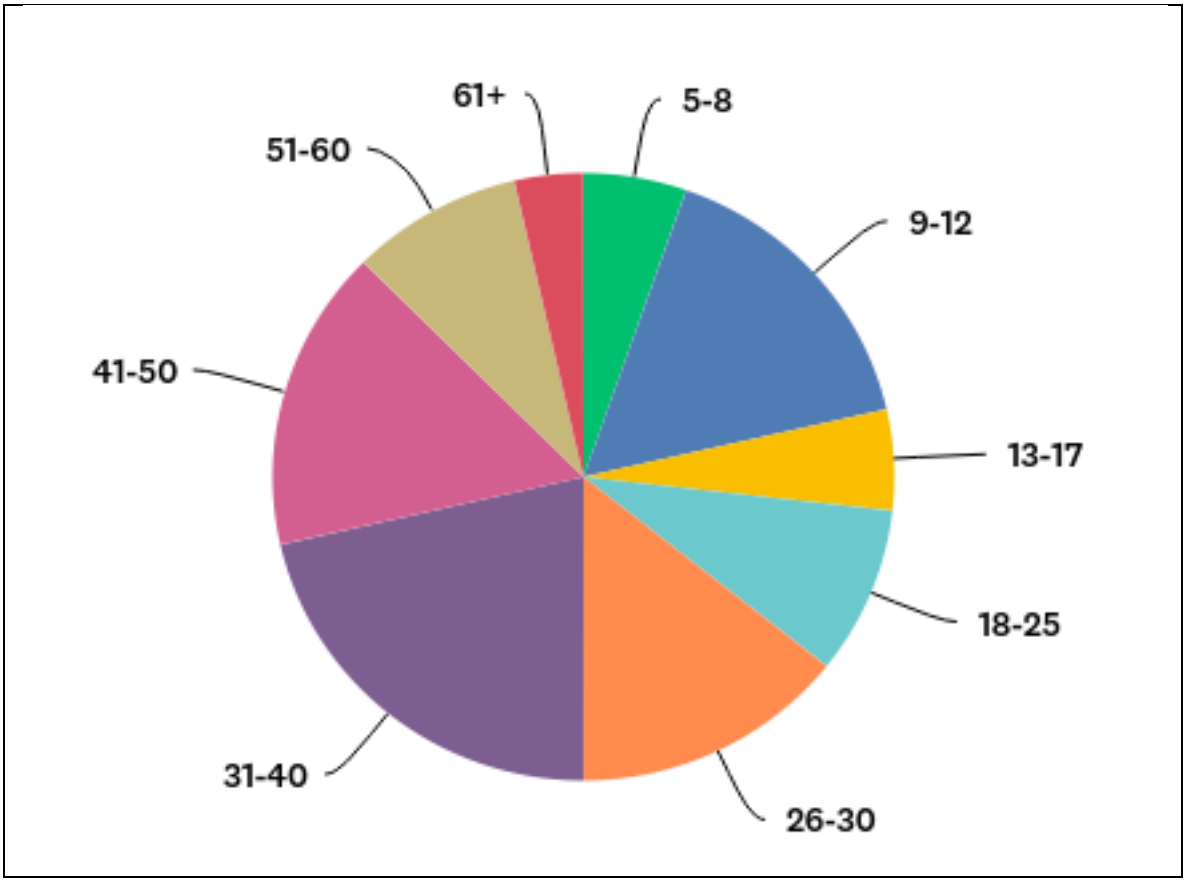
Data Collection	
Day	**Date**
Sunday	October 15th
Sunday	December 10th
Sunday	December 17th

Demographics of visitors, according to data collection method

Naturalistic Observations (N=56): We observed 24 females and 32 males.



Age: Visitors observed ranged in age from 5 to over 61.



Estimated age of visitors in naturalistic observations

The demographics of the visitors recruited for mediated interviews are as follows:

Mediated Interviews		
Age	**F**	**M**
8-10	1	
11-18		1
19-30	2	1
31-40	1	3
41-50	3	1
TOTAL	7	6

Findings and Reflections

In this section we provide findings from the summative study of the Sea of Genes exhibit, and discuss them in relation to the key evaluation questions and the proposed outcomes of the project.

Evaluation Question: What is the nature and quality of visitors' interactions with the exhibits that result from these partnerships?

Project Outcome for Visitors: Engagement, Interest

- Visitors are interested in the topic of ocean environments and marine life

When we study visitor interactions with exhibits, we document several key things -- the context of invitation (is the exhibit inviting to visitors? Is it evident to visitors when they approach the exhibit what the exhibit is about or what they are supposed to do to get started?), navigation (can they interact with the exhibit with ease?), questions and inquiry (can they engage in inquiry using the exhibits, can they ask and find answers to their own questions?), and conceptual understanding (what meaning do visitors make from their experiences with the exhibit?). With this particular exhibit, the documentation of questions, inquiry and conceptual understanding also includes the extent to which the exhibit meets the project's intended outcomes for the public, in terms of skills and awareness, which we will discuss in the sections that follow this one.

In terms of the context of invitation and navigation, the naturalistic observation data show that visitors did not spend much time at the exhibit. Overall, the time visitors spent with the exhibit naturally ranged from two seconds to 89 seconds (with an outlier of 545 seconds), with a mean of 22 seconds, and a median of 9 seconds.

The majority of the interactions we observed naturalistically (30 of 56) lasted 10 seconds or less. For example, 17 of the 56 naturalistic observations that were 10 seconds or less and involved visitors stopping at the table, looking at it, and walking away. Fifteen additional interactions involved visitors stopping, touching the table once or touching the same button in quick succession, and walking away; of these, 13 were 10 seconds or less, while two were 15-36 seconds in length.

An additional 10 interactions involved visitors stopping and reading the text without touching the table; these interactions ranged in time spent from a low of 17 seconds to a high of 89 seconds. These naturalistic interactions raised questions for us about how inviting the exhibit is to visitors, and how easy or difficult it is for visitors to be able to begin to interact with and navigate the exhibit, which we explored through mediated interviews.

Our mediated interviews indicated that visitors could not figure out what to do or where to begin at the exhibit, and were often confused. For example, seven visitors from the 13 groups we conducted mediated interviews with said they were not sure where to start or what to do.

There were only a couple of areas where the visitor could manipulate the image that appeared on the screen (by clicking on the organism or clicking on the dial) – but visitors didn't seem to understand the interactivity, and in particular, that they *could* click on things. The following five vignettes highlight some of the confusion visitors had around where to start and how to interact with the exhibit:

> Visitor group A) A couple (~45 years old) with their son (~seven) and daughter (~12).
> The boy asked, "What do you do with it?" while tapping on the table. The father responded, "I don't think it's interactive, bud," as the mother read some of the text on the left side of the table. The mother said, "Honestly, it's way over my head. I'm interested in what's happening, I just don't know what to do and I can't understand it… I guess there are Sun Harvesters and Sugar Eaters? There is a lot of empty space. I keep waiting for something to happen. My instinct is to ask 'how do I make it work so I can learn something?' – but I can't make it work. So there are three types of genes?" The boy decided, "This is boring."
>
> Visitor group B) A woman (~about 30 years old) with two children (4 and 6).
> First the woman read the panel on the left of the table before trying to interact with the exhibit. Her two children moved on to another exhibit. She asked, "So are these different parts of the water?" while pointing to the screen. "I think it might be confusing to kids. A TV screen explaining it would be better." She also said, "I would like it to be interactive" as she tried to click on the buttons.
>
> Visitor group C) A woman (~35 years old) with son (8).
> She started by reading the title aloud: "A Sea of Genes." Then she pushed on the circular buttons and said, "We're going through the day. The clock is going a little fast for me to understand. Is there something I am supposed to do? There needs to be an obvious start. If there is something I'm supposed to do, it isn't obvious."
>
> Visitor group D) Woman (~20 years old).
> This woman works as a marine educator on a schooner with plankton so she has some knowledge of marine biology already. "I want to click on things to get more information – it would be cool to click on one thing and learn what is inside it and what is coming off of it."
>
> Visitor F) A man (~24).
> The man asked the interviewer, "Does it do anything? What am I supposed to do?" He then clicked on Sun Harvesters and nothing happened. He said, "It's very expensive-looking."
>
> Visitor group G) A man (~40 years old) with his young (~4) son.
> The father asked the interviewer: "What do you do with it? Do you [to the interviewer] know what to do with it?"

Additionally, two of the mediated interviewee groups struggled with how quickly things were happening in the exhibit; several asked for pause buttons. For example:

> Visitor group D, again) Woman (~20 years old).
> Her son started touching the different organisms on the screen. He said, "It's blue when the day comes back." The tab disappeared as the mother was still reading it. She continued, "It disappears before you get a chance to read it. I feel like I would like to pause it because it feels like a lot of things are changing fast. I want to pause it. I think pausing it would be most helpful so I can process one thing at a time."
>
> Visitor group C, again) A woman (~35 years old) with son (8).
> "What might help me is if the clock was slower and if you could pause it, that would be great."

In terms of impacting visitors' interest in marine science, in mediated interviews, four of the visitors we interviewed expressed an interest in the content of the exhibit during the interview, and one young visitor we observed returned to the exhibit, bringing her father to look at it with her. However, given the limited amount of time visitors spent with the exhibit, we are unsure the extent to which it impacted visitors' overall interest in ocean environments and marine life.

Evaluation question: In what ways and to what extent are visitors able to pursue their own inquiries into the data, and in particular, to ask questions and analyze and interpret data?

Project outcomes for visitors: Skills

- Visitors pose productive questions (i.e., answerable with the dataset)
- Visitors answer their questions using the visualization to look at data
- Visitors look at different variables and relationships
- Visitors interpret the data to identify patterns in marine life and environmental factors

In 11 of the 56 naturalistic observations, visitors did more than just read or touch one button, indicating an attempt by visitors at a deeper interaction with the exhibit. Ten of these interactions involved visitors touching the table more than one time, or touching the table beyond just hitting the same button repeatedly; these interactions ranged in time spent at the exhibit from a low of 9 seconds to a high of 78 seconds. The eleventh interaction was the longest one, at 545 seconds, and involved a young girl who had visited the exhibit before who brought her father back with her; they spoke Chinese, so we were unable to understand their conversation or conduct an exit interview with them.

In terms of understanding the extent to which visitors posed productive questions (i.e., answerable with the dataset) and visitors answered their questions using the visualization to look at data, as we described in the previous section, most of the visitor questions we overheard focused on visitors trying to understand how to use the exhibit.

And in terms of understanding the extent to which visitors looked at different variables and relationships, and visitors' interpreting the data to identify patterns in marine life, the most prominent feature of the visualization showed organisms interacting over a period of time, so visitors tended to focus on that aspect, commenting about sequences in organisms' behavior and how one organism's behavior then influences another.

> Visitor group C again) A woman (~35 years old) with son (8).
> "It is interesting because I haven't seen any of this content before. But the information is dispersed and it needs to show more clearly how these three creatures are linked. These three organisms are linked – that is all new information for me."

Visitors tended to pose questions related to trying to understand what it is that they were seeing, not questions that they could use the data to investigate further; here are three examples of that from our mediated interviews:

> Visitor group C, again) A woman (~35 years old) with son (8).
> "So there are different types of creatures – Sun Harvesters and Sugar Eaters. What are they doing at night-time?"

> Visitor group D again) Woman (~20 years old).
> "Are these like plankton? Floaters?"

> Visitor group E again) Young man (~16 years old).
> He said **"**It's overwhelming because there is so much text at once. I'm confused. Are these plankton? The Sugar Eaters are swimming against the waves so they can't be plankton right? Plankton don't do that. Does the sun kill the viruses? Why do the viruses go away? Do they go into these other cells? Is the sugar just free-floating out in the water? Do the Sugar Eaters just smell it and seek it out? How do they ingest the sugar?"

Furthermore, those visitors who did not read the text raised questions about what the visualization was. One visitor wasn't clear whether the organisms were from ocean or fresh water. Another visitor asked if the organisms were in a drop of water being shown through a microscope.

> Visitor F again): A man (~24).
> "It's interesting." When we pressed him to explain or describe what he found interesting about the exhibit, he said, "I don't know. I guess it's telling me the life stories of micro-organisms?" He added, "These are simulations right – it's not a real microscope, right?"

Visitors also had questions about how to decode the data visualization. The dials or circles that represented the actual data (the activation of different genes) were difficult for visitors to decipher. During naturalistic observations, eleven visitors tapped on the circles or held their fingers down on them. During mediated interviews, four visitors thought they were only clocks

– not noticing the relationships between one dial and another. Two others didn't realize the activity represented in the dial was also being represented on the larger screen.

> Visitor group B, again) A woman (~about 30 years old) with two children (4 and 6).
> "It explains what's going on hour-by-hour?"
>
> Visitor group E) Young man (~16 years old).
> This young man shared that he enjoys frequenting science museums and looking at exhibits. **"**Do these dials mean the time? The fact that the dial is a circle makes it seem like a clock."

Evaluation question: What key understandings about ocean science, ocean science research, and data visualization, do visitors come away with from their interactions with the exhibits?

Project outcomes for visitors: Awareness, Knowledge, Understanding

- Visitors understand the connections between marine life and their environment
- Visitors have an awareness that scientists study oceans by collecting and examining data

In terms of the extent to which the exhibit helps visitors understand the connection between marine life and the environment, the title of the exhibit (A Sea of Genes) is helpful for supporting visitors' understanding of ocean ecosystems; yet, not all visitors notice the title. Those few visitors who did spend time with the exhibit (after we asked them to) understood that the organisms were part of an ecosystem, and that the existence and behavior of one type of organism influenced and was influenced by the existence and behavior of other organisms.

> Visitor group D again) Woman (~20 years old).
> "It feels like things are getting eaten and the sun is an important part of it."

The vignette on the following page highlights the best-case usage we saw of the exhibit. The daughter used the phrase, "I activated the gene," but did not know what that meant. It is not clear that they came away from the exhibit with an understanding of what the data being represented are, or what gene activation means in this context. It could be argued that they came away with an understanding that these organisms interact with each other but we cannot say for certain they understood that these organisms were from an ocean ecosystem.

> Visitor group G) A father (~35 years old) and his daughter (8).
> The daughter began by telling us, "I'm into bacteria" before pressing on the buttons. She said, "I want to make them split. I activated the gene… what does that mean? I'm going to activate all the genes." The father asked her to read the panel and she read all of the text. He asked her questions along the way such as: "We saw something that releases sugar, what was that? So these guys (the Sun Harvesters) make sugar, which creates a good environment for the Sugar Eaters, right? What's going on with these viruses?" The daughter responded, "They infect green Sun Harvesters." Then the dad

noticed the cycle repeating: “Oh, look! We’ll watch that whole process again. Viruses are making copies of themselves inside the Sun Harvesters.” The daughter observed, “The triangles are the sugars” and the dad exclaimed, “Oh! The triangles are the sugars!”

In terms of the extent to which the exhibit helped visitors have an awareness that scientists study oceans by collecting and examining data, two visitors we spoke with in mediated interviews about the text understood that scientists collected data while on boats, and that something about what they collected is represented on the screen of the table. However, they did not identify the activation of genes as the data that was represented.

As one final example, we share this vignette of a visitor who brings science knowledge to the exhibit, and yet still had trouble making sense of what the exhibit was trying to show:

> Visitor H) A woman (~50 years old) who is a 7th grade science teacher.
> This particular woman had a firm understanding of genes already, given her experience as a middle school science teacher. She spent 13 minutes trying to figure out the exhibit and offering her impressions of it. Here is her running commentary, including the many questions she had while using it. First she said, “I don’t like the title because those are not genes. Sun Harvesters and Sugar Eaters are bacterial. It should clearly say that since Cyanophages are viruses. The picture is too vague. SAR116 should be next to the picture.” While looking at the dial, she said, “Does this mean that the higher up they are, the more active they are? Is this in real time? Like right now? This is a simulation right? I don’t know… is this supposed to be one bacteria? If this were a colony it would all be lit up. This should be clarified: are these active genes of one bacteria? It would be good to show what these other things are. The dial does not make sense to me. Where is the feeding portion? When do they get the energy? This suggests that while they are dividing, they are not making sugar. Is that true? I didn’t even notice the timeline part of it. The exhibit is trying to do too much at one time. The word photosynthesis needs to be in here somewhere. They are getting energy from the sun. There is no time for ‘growing’ – maybe that’s what ‘dividing’ is? Is it really ‘resting’? It says ‘they infect’ so then the visitor has to go back and figure out what ‘they’ refers to. I wonder if it is better to just have the cycle of one organism at a time – a button for just one at a time, and if they don’t hit a button, they see all of it. When do Cyanophages come out? Here they are coming out at night so they infect only at night? So is the exhibit showing how they infect the bacteria? It needs to be simplified… what are the priorities here? Is it the time of day? Is it the difference between viruses and bacteria? There are too many layers. Or there need to be several different keys and legends to provide clearer explanations. It’s confusing.”

Summary

In summary, our naturalistic observations showed that visitors did not spend a great deal of time at the exhibit. Most visitors who approached the exhibit looked at the table, or touched one button, and walked away. Both our naturalistic observations and mediated interviews

showed that visitors didn't understand where to start or how to interact with the exhibit. And while the visitors in our observations and mediated interviews raised a lot of questions, they were mostly related to trying to understand what it was that they were seeing, not necessarily questions they would use the data to find the answers to. Those visitors who did spend time with the exhibit (after we asked them to) understood that the organisms were part of an ecosystem, and that the existence and behavior of one type of organism influenced and was influenced by the existence and behavior of other organisms. Beyond that, we don't have much data to support that visitors were able to understand what the exhibit was trying to show them, let alone make the bigger connection to how scientists collect and use data and the relationship between marine life and the environment.