The Promise and Realities of the Use of Cyber Technologies for Promoting Research in Public STEM Museum Experiences.

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Abstract

A seven-year effort funded by the United States' National Science Foundation and the Oregon Sea Grant College Program sought to identify and deploy in a public STEM museum setting a suite of digital tools for collecting and supporting analysis of data on the use of the setting in near real time and as evidence for *in situ* learning. In addition to full-museum camera coverage and data collection, five exhibit-based research platforms were developed to allow for collection of linked video, audio, and digital input (keystroke, touch screen manipulation) data at particular locations in the museum. A further effort explored the use of social media data mining tools as well as apps for research on how learners create continuity across STEM learning experiences distributed temporally and geographically. Returns on investment for research on informal learning were proven to be high with signifiant gains for researchers working with the museum and for building research partnerships with other museums and informal STEM learning environments (e.g., Maker Faires, public exhibits, tourism in marine environments), but return on investment for museum operations and programmatic advancement were relatively minor. While the project proved that a public museum can successfully employ current video-based, cyber-linked technologies to document and study learning outside of a laboratory setting, it also demonstrated that such activity is most likely beyond the budgetary and information technology capacity of most public institutions. However, the project also piloted and provided proof of concept for smaller, mobile efforts using many of the same technologies and tools in scaled-down but efficient research and evaluation efforts.

Keywords: Cyberlearning; Informal Learning Environments; STEM; Video-based Research

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In 2011, Oregon State University (OSU) and Oregon Sea Grant were awarded an Advancing Informal Science Learning Full Scale Development grant by the National Science Foundation that allowed for the exploration of new tools and technologies for research with human beings as learners in everyday learning experiences and their integration into a public museum space. The resulting Cyberlab, which made possible the installation of an observation system that allowed for the instrumenting of an entire museum (Hatfield Marine Science Center Visitor Center) at OSU's marine science campus in Newport, Oregon, was modeled on the use of remote sensing in natural and behavioral sciences and represented an attempt to provide data useful for both the deep, qualitative analysis typical of informal STEM learning research, and "big data" representative of large-scale patterns of use and impact for the visiting public. While the original goals of the project were to create opportunities for studying the roles of continuity and customization in visitor learning in the museum context (and beyond the visit) (Rowe, et al., 2016), the actual research questions were meant to emerge from the everyday practice of developing and maintaining exhibits and programs in a public STEM museum. Thus, while not explicitly funded as such, the Cyberlab (and its parent lab, the Free-Choice Learning Lab) serve as one way to realize a research in service to practice partnership (Gutwill, et al, 2015; Bevan & Penuel, 2017) — embedding the research enterprise directly into the day-to-day management of the museum.

Setting the Stage

The Free-Choice Learning Lab at the Hatfield Marine Science Center Visitors Center

Oregon Sea Grant's Free-Choice Learning Laboratory (FCLLab) is situated at the Hatfield Marine Science Center (HMSC), an OSU marine science research facility on the West Coast of the United States housing a Visitor Center (VC) that functions both as a public science museum/aquarium and as a laboratory for studying self-paced, leisure-time, lifelong learning. FCLLab research in the VC focuses on learning activities that take place outside of classrooms, are self-motivated, and are guided by the needs and interests of learners, focusing on how people learn through these activities, both as individuals and as groups. Findings are meant to inform better educational and research practices in informal science education venues as well as the practice of public science communication broadly.

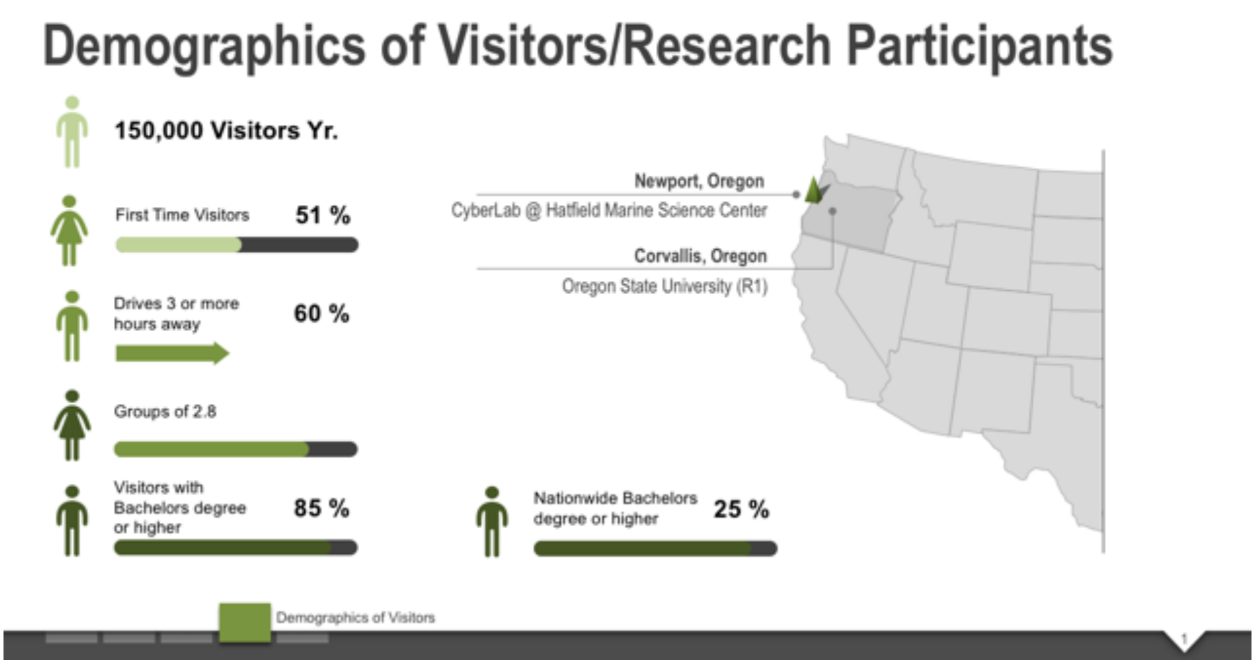

Figure 1. Location and basic visitor demographics for Hatfield Marine Science Center, from Rowe, S.M. (2017).

The HMSC campus houses university, state and federal agency researchers, educators, and outreach specialists. The VC serves a public audience of approximately 150,000 people a year as a donation-only, interactive, science center and aquarium, highlighting the research of scientists on site through a combination of computer-based, physical interactive, and live animal exhibits. Newport is a summer vacation destination, and, as Figure 1 shows, most visitors are non-local. Since 2004, the FCLLab has been housed in the VC working to develop a culture of evaluation and research surrounding informal, free-choice science learning on site as an integral part of the day-to-day operations of the VC.

The Fully Functioning Cyberlab

In 2011, NSF funding made it possible to reimagine the VC as a site for the collection of large amounts of digital data about use and users to demonstrate whether and to what extent off-the-shelf security and data analytics packages could be used to augment the labor intensive video-based and observational data collection typical of much museum learning research. At its core, the resulting Cyberlab's research tools and technology platforms were comprised of three separate but interrelated systems: a video-based observation system, an observational control system, and a database. Fully automated, video and audio-based observation systems were the central tools to record visitor interactions in varied levels of researcher-controlled detail. These observation systems were designed to work independently or in conjunction with the control systems (described below), which could be configured to trigger data extraction or (potentially) exhibit content changes based on output results from the observation systems.

At full deployment, over 40 surveillance cameras were installed throughout the exhibit spaces and recorded a constant flow of video perspectives of both micro and macro level interactions between visitors and exhibits, among visitors themselves, and between visitors and staff. The cameras were fully adjustable to allow for future exhibit changes or research developments. Microphones were also installed in concentrated areas to capture usable, clear dialog linked with multiple video feeds. Video and audio streams were tied to a Video Management System (Milestone), where the feeds could be organized into “views” that were made up of similar exhibits or customized to a particular project for both naturalistic/descriptive and quasi-experimental research (see Figure 2). Users (e.g., cyberlab staff, visiting researchers, students, remote partners) could view the feeds in real time or use the playback option to filter through recent recordings. This option also allowed users to adjust the speed of playback and work within a visual timeline to identify precisely exact moments or interactions for further analysis. Over a 20-day recording period, the system logged over 64 Terabytes of A/V data. Any video desired for research was meant to be downloaded to remote servers during this 20 days. At the end of 20 days, existing footage was removed from servers by writing over.

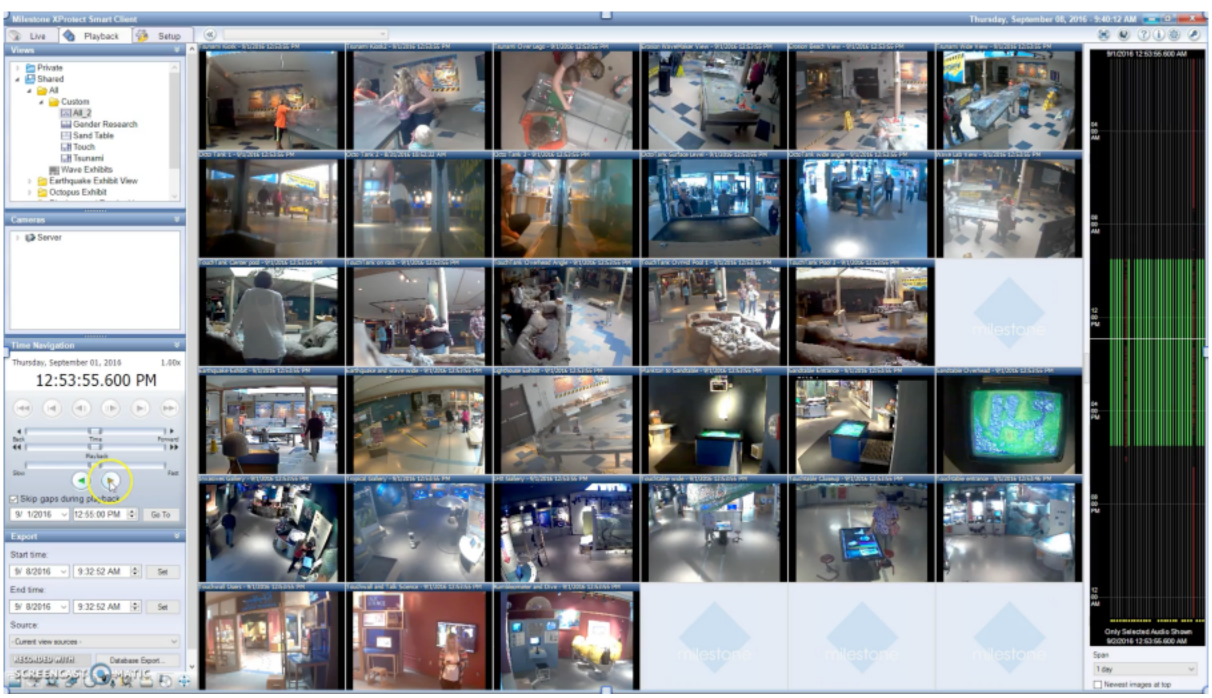

Figure 2. The Milestone software user interface in playback mode showing 32 camera views as well as navigation, flagging, and exporting tools.

Surrounding these core observation systems was a suite of other tools to assist in research: body cameras, specialized video analytics packages that could be focused on a specific space or a specific question, mobile microphones, and tablets for inquiry and survey work. Body cameras were used to capture point-of-view videos on visitors, staff, or research participants (as reported in Good, 2013). The Video Management System (mentioned above) included software add-ons and analytics, to allow for "filtering" and "flagging" of raw video data. Using these software packages, for instance, researchers could set up motion detection in a particular area of the frame to detect a special event (e.g., a visitor pulling a lever or using the touch pool). Specifically, on detection of a motion, the software could record the "event" and bookmark it based on prior instructions.

In addition to the cameras focused at specific research platforms, Cyberlab also employed cameras throughout the entire museum to do basic tracking, visitor counting, and to produce data visualizations of use of particular areas. Such cameras employ on-board analytics that use frame-comparison algorithms to map out the "hot spots" of activity in the frame. These maps could be used to allow a researcher to quickly and holistically assess where large portions of visitors stop or travel through (Figure 3). The same cameras had the ability to set up "counting corridors" in the frame, to count how many people move through a particular plane. These raw numbers delivered could then be broken down by month, week, day, or even hour to show the number of people moving through a particular space. Data was reported through pre-packaged user visualizations as well as available for CSV export (Figure 4). Mobile microphones could be set up for interviews or feedback sessions, or passed on to a group traveling through the VC to capture their discussions in-between stations.

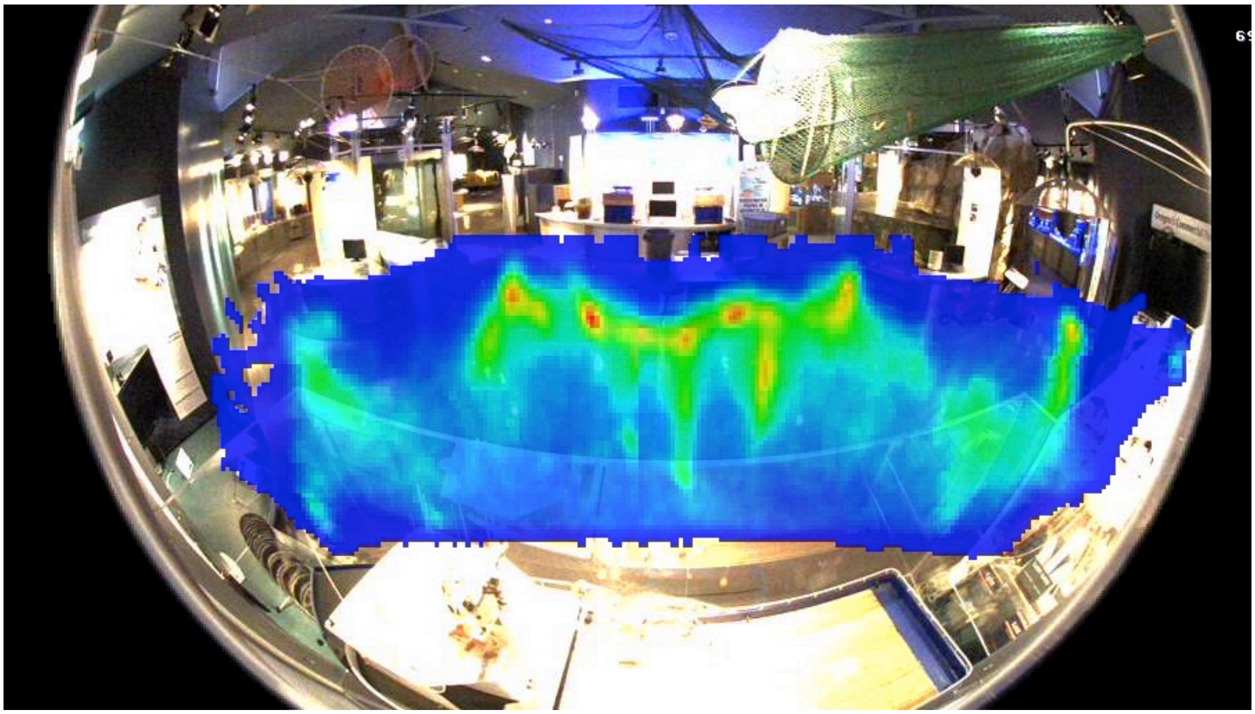

Figure 3. Example of on-board camera visualization of "holding power" – the length of time visitors stand in front of particular exhibit components — available in near real time or as a report.

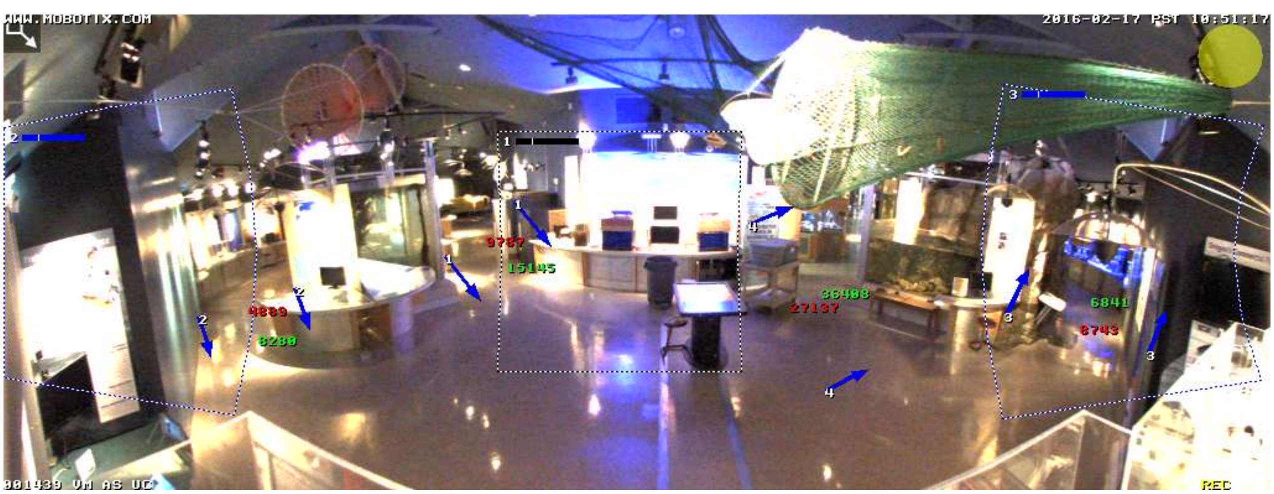

Figure 4. Example of on board computing of visitor tracking using ″counting corridors″ — numbers of individuals moving and direction of movement through a researcher-defined area — from the same camera shown in Figure 3.

A separate network of specialized cameras worked with software to detect facial features in a video frame. The software was designed to scan footage for generalized human features, then identify up to 70 unique points on an individual's face. Once this pattern was captured, it could be compared to other facial patterns picked up by the system. The goal was to match a person's face to all other instances of it in the camera network, building a time-stamped "map" of where an individual had been during their visit to the visitor center. When the pattern was captured, the software also estimated age, race, and gender and liked that data to the facial pattern. Only the pattern and this demographic data were captured, and each identified individual was given a random identification number, ensuring that the information gathered remains anonymous. This information was then used to produce time and tracking data for both groups of visitors and individual visitors. Because an individual's face was captured at multiple points throughout the visitor center, the database could automatically calculate the total time of an individual's visit, as well as where they spent that time. At the largest deployment of face detection and recognition work, over 15 cameras were spaced around the donut-shaped VC, positioned at key transitions between exhibits (see Figure 5, VC floor plan with face detection zones). This allowed the research team to divide the space into virtual "rooms," with the cameras at the entries and exits. With the cameras grouped by room, researchers worked to attribute a location to each time a face was recognized. The cameras were running constantly, capturing hundreds to thousands of facial patterns each day. Based on this information, researchers were able to produce reports demonstrating the trends of visitors across multiple demographic groups.

For example: we could quickly identify which areas attracted younger visitors, and also areas in which people spent the least amount of time.

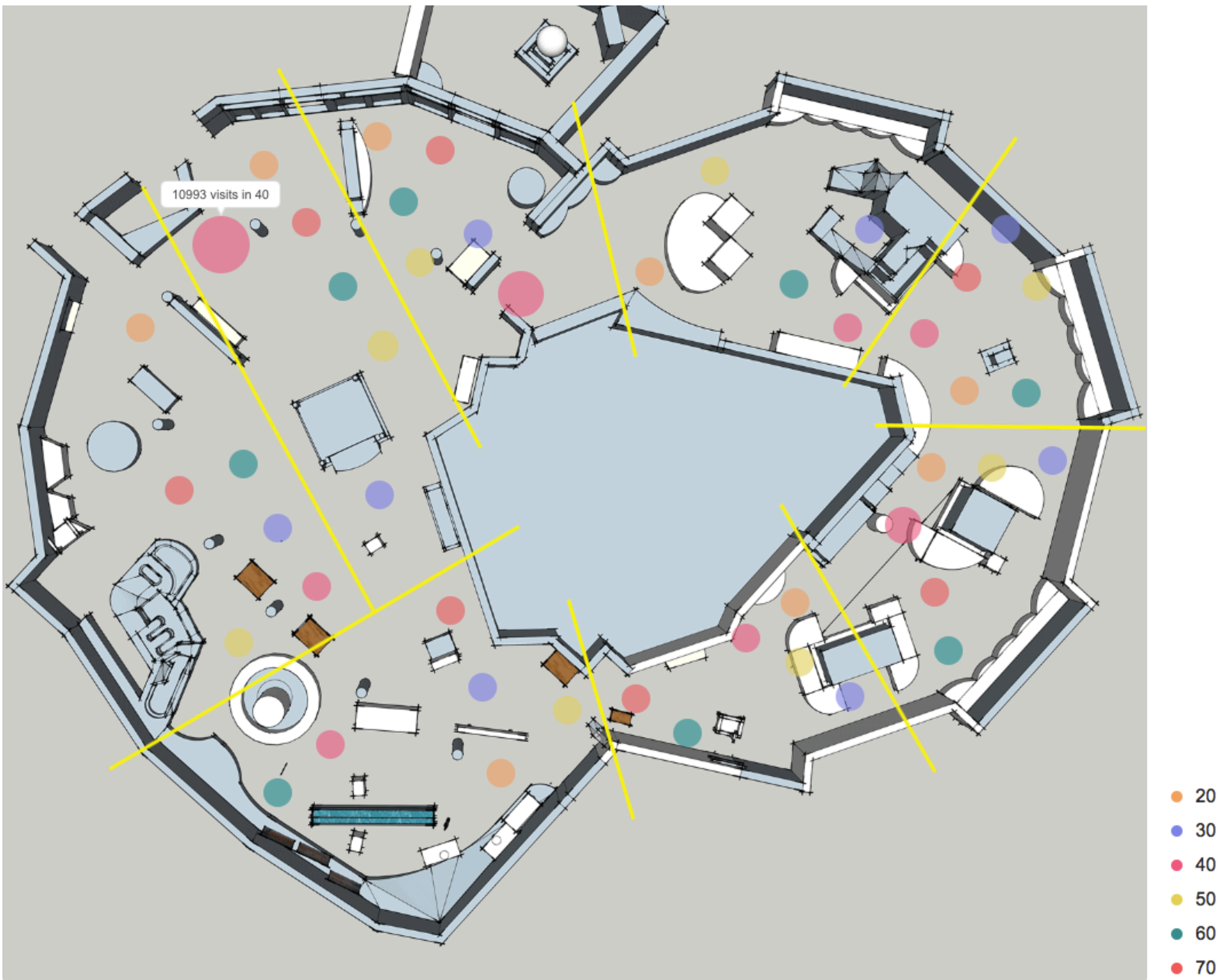

Figure 5. HMSC VC floor plan showing virtual rooms defined by entry and exit point face-detection cameras along with visualization showing number of male visitors in each of 6 age categories present in each room over the course of one day.

Because of its use of cloud computing technology and internet services, the entire Cyberlab could be made available remotely to researchers anywhere in the world who wanted to work with OSU staff to identify needed camera views and other data streams as well as set up experimental conditions on the floor of the museum for data collection. This ability to conceptualize a study and carry it out at distance opened new avenues for nationwide and international collaboration on informal STEM learning research.

The following sections describe in more detail the research platforms created or adapted for the Cyberlab project as well as work with social media and mobile Cyberlab deployment meant to support collaborative research outside the walls of the museum. This is followed by an exploration of lessons learned from the entire project as well as a brief outline of the potential and challenges of ongoing research efforts building off of the initial NSF Cyberlab investment.

Research Platforms

From 2010 to 2018, five exhibits were constructed or adapted to serve as "research platforms." Research platforms were designed to allow for observation of a wide variety of typical visitor learning arrangements, interaction types and genres, STEM content areas, and researcher agendas while specifically allowing researchers to easily manipulate all aspects of visitor interaction and capture that interaction with audio, video, and visitor/computer interface data as part of the Cyberlab.

Touch Tanks

Figure 6. HMSC touch tanks as seen from a Cyberlab camera. To the left is a volunteer interpreter standing in an area behind the tanks generally reserved for staff or volunteers here

While pre-existing the development of the Cyberlab, the touch-tank exhibits at HMSC VC have served as a significant research platform for a variety of studies (Kisiel et al., 2012; Kopczak, 2012; Kopcack, et al.,2013; Rowe and Kisiel, 2012; Good, 2013; Rowe, S.R.M, 2019). The touch-tank has a naturalistic design to resemble local natural tide pools and is divided into four sections with different heights allowing access to children and adults (See Figure 6). While there, visitors have access to one side of the tank and can roll up their sleeves to touch a variety of North Eastern Pacific invertebrates and vertebrates including sea anemones, sea stars, abalones, sea urchins, etc. On the other side of the tank, volunteers are generally stationed to facilitate the visitor experience by engaging in conversations, answering questions, explaining rules for touching the animals, etc. It is a very popular exhibit with approximately 70% of visitors interacting with the tanks and animals contained within them for more than 30 seconds and generally ranging from just under five minutes to around 20 minutes (Rowe & Kisiel, 2009), yet some individual families may spend up to 45 minutes at the touch tanks, a significant portion of their (on average) two-hour visit. In studies dating from between 1992 and 2012 (Gaughan Tissot, 1992; Lynds, 1998; Rowe & Kisiel, 2012), no other live animal or interactive exhibit at the Visitor Center showed equivalent attraction and holding powers. The setting is, thus, an ideal place to study family visitors, interactions with animals and staff, and a wide variety of environmental and STEM related teaching and learning concepts. With Cyberlab support, the touch tanks have been used to study volunteer-explainer communication strategies (Good, 2013), family biological and ecological talk (Kopczak, et al., 2013), general patterns of engagement as well as scientific observation and reasoning among families (Kisiel, et al., 2012), and family conservation talk (Rowe, S.R.M., 2019).

Wave Tanks

Figure 7. Wave Tank Research Platform. Sediment transport (right) and extraction of energy from ocean waves (left) exhibit components are in the foreground. The Build-and-Test tank is in

the background with touch screen controller, Lego-brick platform, signage, actuators, and data collection video and audio installation visible.

NSF support allowed for the planning, construction, and installation of a wave tank research platform consisting of three interactive exhibits made up of wave generator tanks, signage on wave energy physics and social and ecological impacts of wave energy extraction, video and signage about earthquake and tsunami risks locally, and information on sediment transport as well as coastal erosion and erosion mitigation. The entire exhibition area was designed to allow researchers to focus on collaborative and competitive aspects of exhibit engagement especially related to tinkering, a topic of growing interest in informal STEM learning especially related to museums (Gutwill, et al., 2015; Bevan, et al., 2015; Martinez-Maldonado, 2014; Mostov, 2014).

Tsunami Tank. The centerpiece exhibit consists of two long “flume” tanks with mechanical wave activators at one end operated by touch-screen computer kiosks that allow visitors to control type, size, height, and frequency of waves to be generated. At the opposite end of each tank, a raised platform is fitted with a Lego-brick base upon which visitors are challenged to “build something that will withstand the energy of a tsunami wave” (https://seagrant.oregonstate.edu/visitor-center/exhibits) using Lego bricks. The Legos hanging in tubs on the side of the exhibit have been modified (differentially weakened) to represent building materials with different strengths (i.e., white bricks represent concrete, black represent steel, and red represent wood). After building (or often during the process), visitors use the computers to create a wave in the tank and observe the impacts of the wave on their structure. There are two identical wave tanks situated side-by-side to accommodate multiple groups. This tank has been used to study collaborative and individual tinkering activity in a destructive build-and-test scenario (Rowe, et al., in preparation). The long-flume build and test tank has been reproduced twice by the Coast Guard Training Center and the Beaverton Oregon School District.

Wave Energy Tank. A second flume-type tank with a manual wave activator allows visitors to generate electricity via a point-absorption type wave energy extraction bouy model. The lid of this tank may be removed so that small, organized groups (such as school classes or after-school clubs) who have previously built their own wave energy absorption model devices developed by the museum and disseminated through the Pacific Marine Energy Center (https://www.pmec.us/education-outreach) can test them by generating waves in the tank and recording performance on a laptop.

Erosion Tank. The final tank also includes a manual wave activator, sand and water. Child fist-sized rocks, duplo building blocks, and similarly sized nets filled with small rocks represent a variety of materials visitors may employ to mitigate beach erosion through beach armoring, use of riprap or dynamic revetment. As the tank is both wide and long, interaction with it generally requires some level of collaboration among visitors in the same group or across multiple groups.

Multitouch Table and Wall Mount

The presence of interactive tabletops in some museums and galleries dates back almost a decade, allowing guests to explore the representation of cultural artifacts or science phenomena in a different way (Geller, 2006; Hornecker, 2008). Ranging in size and shape, these exhibits showcase the advancement of touch technology and the ability to support multiple users at the same time. Unlike a desktop computer, the table format allows for visitors to gather around, orient themselves face to face, and have the potential to collaborate over a large surface, all elements that can support family learning (Borun, et al., 1997; Geller, 2006). With a touch response like a tablet or smartphone, visitors can use one or two hands to manipulate objects on the screen. Gestures may include dragging, enlarging, shrinking, or rotating an object depending on the goal of the user and the design or function of the content. The Cyberlab includes a A 55” Ideum multi-touch tabletop exhibit, approximately the size of a small kitchen table that four people can comfortably stand around and use at the same time (see Figure 8). The multi-touch table exhibit has been customized for HMSC to include four microphones to audio record visitor conversations. As a research platform, multi-user digital touch interface provides a unique platform for research with groups in informal science settings. As an exhibit it can communicate and visualize science content to display, enhance, and supplement information in an attractive way. Research with the table has focused on family collaborative activity (East, 2015) as well as visitors’ perceptions of climate change and best avenues for engaging them in interaction with climate science (Nance, 2013).

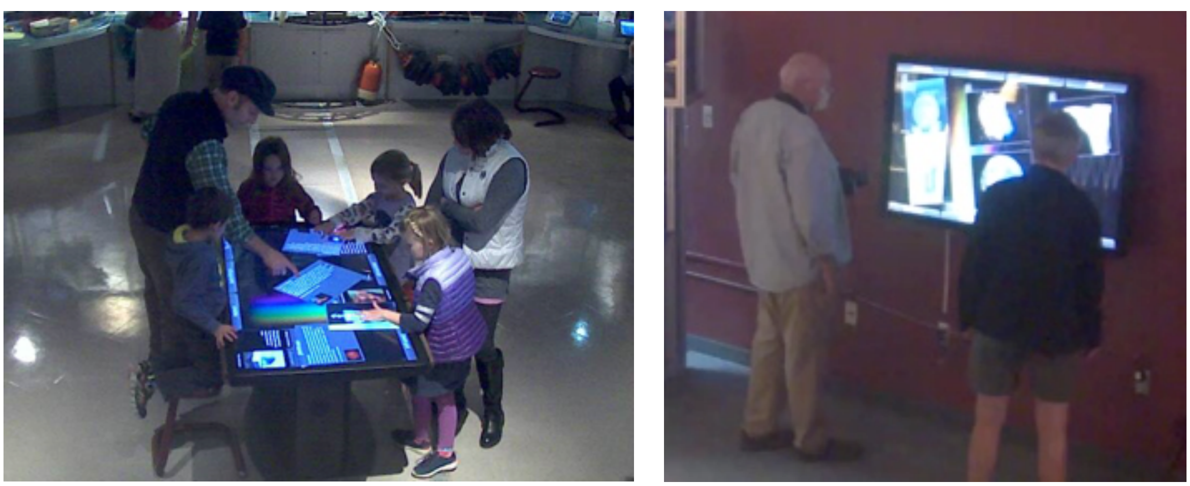

Figure 8. The Ideum 55″ multi-touch tabletop with the electromagnetic spectrum software exhibit mounted as table top (left) and as wall unit (right) seen from Cyberlab camera installations.

Spherical Display

A Global Imagination one-meter Magic Planet Digital Projection Globe initially funded by the National Oceanic and Atmospheric Association (NOAA) was adapted to serve as a Cyberlab initial research platform from 2011 until it was decommissioned as an exhibit in 2015 (see Figure 9). The spherical display system was part of a larger exhibition, Rhythms of Our Coastal Waters, made up of five exhibits sharing a remote sensing theme. The exhibition was intended to increase visitor awareness of remote sensing and content related to ocean and climate sciences and included the Magic Planet, an interactive touch screen exhibit involving plotting real time, local (estuarine) water quality data (including chlorophyll, dissolved oxygen, turbidity, salinity, and temperature) (Mikulak, 2009), a wind speed activity involving a computer plotting data from an anemometer manipulated by fans, an interactive-computer exhibit showcasing the NSF-funded work of CIOSS (Cooperative Institute for Oceanographic Satellite Studies), describing the use of satellites and shipboard sensors to gather the kinds of data projected on the globe and putting the local Yaquina Bay data into a regional perspective; and an exhibit on the NSF-funded regional ocean observation systems work done in the Pacific Northwest by OrCOOS (Oregon Coastal Ocean Observing System) and NANOOS (Northwest Association of Networked Ocean Observing Systems).

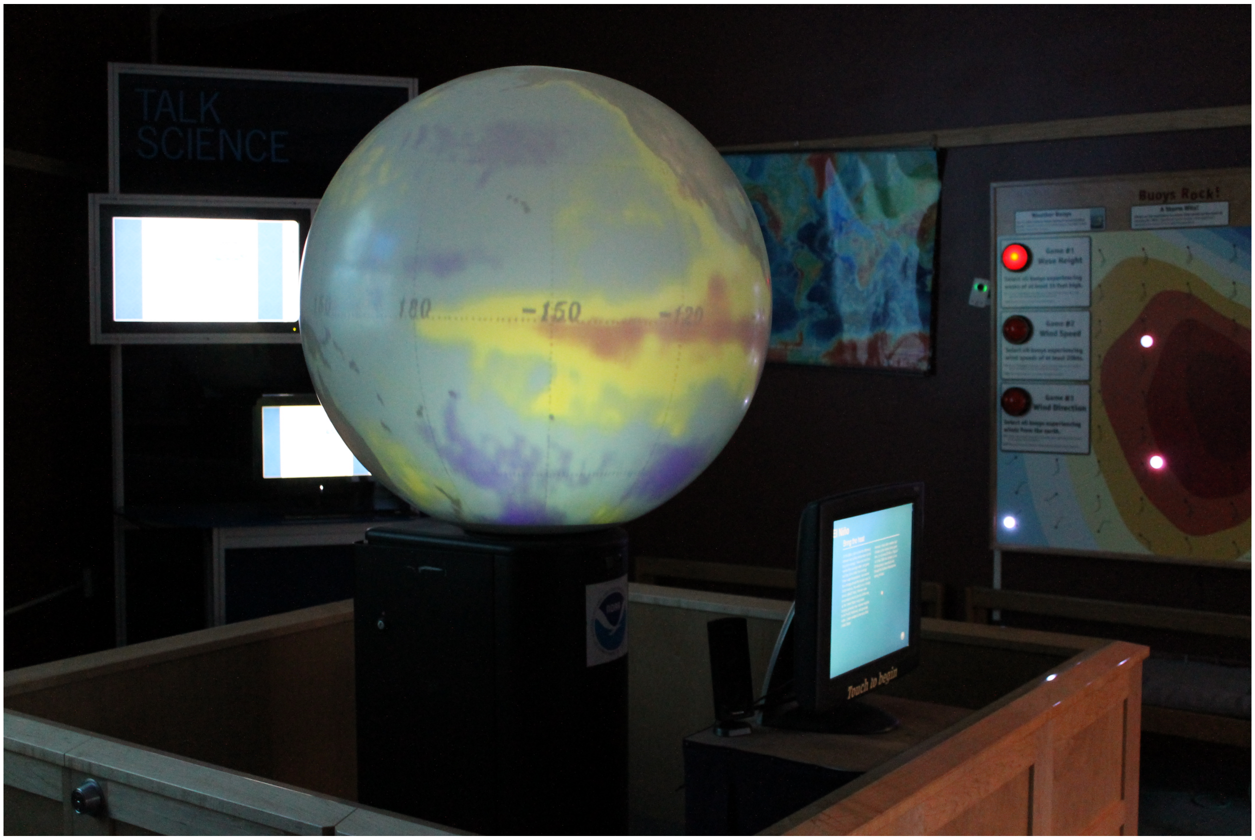

Figure 9. Global Imagination 3 meter Magic Planet spherical display system in the context of other Rhythms of our Coastal Ocean false color data visualization exhibits showing El Niño data visualization. The touch screen kiosk inside the box and visible to the right of the sphere allows visitors to choose multiple views, content, and manipulate the orientation of the image on the sphere.

The Magic Planet content was designed specifically to showcase data (much of which was processed by OSU scientists and technicians from satellite and global bouy data) and the phenomena that data describe through captivating animated images, supportive text, and narration highlighting local, regional, and global research. Each ‘story,’ chosen from a interactive touch screen menu, addressed complex phenomenon such as ocean and atmospheric interactions, climate change, natural hazards, or ocean temperatures with false color visualizations and a variety of tools designed to scaffold (Wood, et al., 1976) visitors' interactions in ways that would be both intuitive and engaging. Reflective video-based observation using Video Traces (Stevens et al., 1997) allowed for research exploring visitor engagement with and sense making from the multimodal exhibit experience (Rowe S.M., 2012). Research with ocean science experts and non-experts (both non-ocean science undergraduate students and visitors to the museum) employing eye-tracking in both laboratory and in-situ (on the museum floor with the spherical display system) conditions explored the role of visual scaffolds (Phipps and Rowe, 2010) in supporting both expert and novice meaning making from false color data visualizations (Stofer, 2013).

Augmented Reality Sand Table

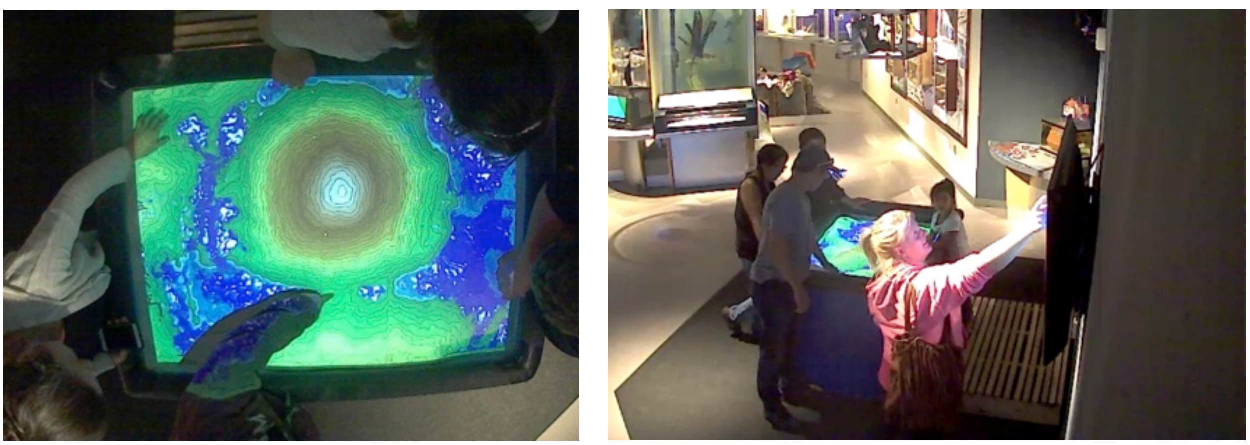

Figure 10. Augmented Reality Sandbox seen from above (left) and in context (right).

In 2016, the project acquired from the University of California, Davis an NSF-funded Augmented Reality Sandbox (http://idav.ucdavis.edu/~okreylos/ResDev/SARndbox/), which was modified and installed on the floor of the museum as an additional research platform. Initial data collected from the AR Sandbox exhibit is allowing project affiliates to extend our existing body of work on collaborative activity such as that documented at the touch tanks, wave tanks, and multi-touch table exhibits described above. It is also allowing us to develop new questions about learning from data visualization, modeling, and expert/non-expert interaction around complex objects, building on the work previously carried out with the spherical display exhibit and eye-tracking research described above.

Social Media Data Mining for Learning Ecology Research

Part of the original justification for the award of the Cyberlab grant was to explore the use of cyber technologies for supporting research on how learners create continuity across multiple learning experiences disbursed both temporally and geographically (as reported in Rowe, et al., 2016). A commercially available social media data mining service (WeLink) was employed as a tool allowing users to choose a geographic location and sample publicly available social media posts geotagged to that area. Pilot projects were designed to determine 1) if project researchers could, in fact, identify and track public perceptions of places and events related to STEM learning, 2) if project researchers could identify “local” users who intercept the STEM teaching and learning sites and events supported by the Cyberlab grant frequently as well as “tourists” who intercept infrequently, but might visit other, non-local STEM sites and experiences and post about them, and 3) if this work could be aligned with work on tourism and economic impacts of tourism to broaden our understanding of motivations for and impacts of visits to informal STEM learning centers like museums, zoos, and aquariums. The pilot work demonstrated that it was, in fact, possible to achieve all three goals.

Developing a Mobile Cyberlab

Midway through the project, it became clear that full-scale installation and implementation of a video-based, remote sensing system for visitor studies would be beyond the fiscal and IT capacity of most public STEM venues such as museums, zoos, and aquariums.

There was, however, significant interest from both researchers and practitioners working with and alongside the project in the possibilities of building and deploying smaller-scale, mobile versions of the Cyberlab. Several different mobile systems were deployed from 2016 to 2019, each customized to solve particular data collection and analysis problems.

In conjunction with researchers at the Oswaldo Cruz Foundation (Fiocruz) and the Museo da Vida (both in Rio de Janerio, Brazil), three exhibit-based research projects have been carried out. The first employed both exhibit-mounted (Axis Brick) and visitor-mounted (Go-Pro) cameras and audio to explore family interactions within a ecosystem biodiversity exhibit (Floresta di Sentidos — Forest of the Senses) and is the subject of a doctoral thesis currently under preparation (Neves, in preparation). A second also employed participant observer mounted Go-Pro cameras in a traveling health and human anatomy exhibit in Brazil (Aventuras de corpo humano — Adventures in the Human Body) to explore the role of museum mediators (staff) and exhibit structures in supporting or undermining visitor agency (Massarani, et al., in press). Cyberlab project staff have also been involved with the use of a similar system to study the use of interactive museum exhibits by adolescents in Columbia (Massarani, et al., in press). A second Go-Pro based mobile Cyberlab was also developed and deployed both for student research in the HMSC VC (Darr, 2019) and for pilot research at a science and arts festival and a maker Faire event on the OSU campus. This proof of concept was subsequently expanded and deployed by researchers from the OSU Center for Lifelong STEM Education Research as part of two NSF-funded projects with zoos and aquariums (https://wzam.org/what-about-zoos-and-aquariums/).

Lessons Leaned

Infrastructure needs

Cyber infrastructure and support proved to be the most significant hurdle for the project. The HMSC VC is physically located in an R1 university facility with substantial wireless and cabled data infrastructure. However, as the "public wing," priority had never been given to ensuring the reach of that infrastructure into the museum. Significant cost and justification was required to generate the needed level of infrastructure investment and IT support time to make the project a reality and for ongoing growth and maintenance. In early attempts to find mobile Cyberlab solutions for other sites, the same two issues continuously arose: there was never enough band-width for video collection and analysis, and there was never enough IT support "in house" for installation and maintenance even of a temporary deployment. In the full deployment, video was served directly from cameras to colocated central servers for temporary (20 day) storage (64 Terrabytes every 20 days), processed and flagged by a second set of servers, and clipped for delivery to permanent storage by a third. Our current mobile solution collects data on board all cameras and requires a download to permanent storage once the onboard memory is filled. It then requires researchers to manually sort through the data for quality assurance, flagging, and reduction before analysis. The capacity to create a mobile version of the back-end data handling and analysis software and hardware does exist which would allow a fuller realization of the potential of the mobile solution, but the cost and IT support (outlined in Appendix A), again, are most likely prohibitive for most public STEM applications.

The Challenge of Numerical and Video-Based Data

A significant effort over the entire life of the Cyberlab went to working with potential users (both museum education and evaluation practitioners and researchers) to imagine and carry out their own projects using the system. Most of the professionals who worked with the Cyberlab over that time were not well-prepared to work with big data or to develop the sorts of researchable questions that large data sets of remotely sensed data could address. As a result, very few projects actually used the large data set of information extracted from video or the flagging systems put in place to automatically identify portions of video for further analysis. As a result, most of the actual numerical data collected as part of the project has never been seriously queried or used. Participating professionals were excited to have access to high-quality, multi-view video of interactions at exhibits with good audio, but most also did not have direct experience using software to analyze video. As a result, we found it necessary to create professional development opportunities in video analysis for researchers (both student and professional) who used the Cyberlab for video data collection.

Return on Investment for Research and Practice

Embedded in the work of the museum and overseen by museum-based research and programming staff, the Cyberlab project proved the efficacy of using video-based data collection and automated data analytics for documenting and improving learning experiences in a public STEM venue. In addition to the many research projects pointed to throughout this report, we also carried out numerous evaluation efforts (both formative and summative) as part of the day-to-day operation of the museum. Signs and interactive were prototyped; movement patterns were mapped to identify new exhibit replacement; crowdedness monitoring allowed for mitigation of pressure on particular exhibit components (especially live animals) during high crowding. In short, much of the day-to-day work of formative evaluation and needs assessment was streamlined and facilitated by the Cyberlab system. However, as the original NSF funding for the project ended, the museum itself simply could not justify the ongoing expense of maintaining (and eventually updating) the infrastructure, the software licensing costs, or the dedicated IT support costs. The high cost of these “additions” to the regular expenses of running a museum could not justify the evaluation and visitor studies outcomes they generated. The return on (substantial) investment was too low.

In contrast, the return on investment for research was quite high. The OSU HMSC VC has been considered a social learning laboratory since at least the late 1990’s, and its role as an informal STEM learning sciences research lab was formalized by establishing the FCL Lab as an integrated component of museum operations in 2004. The NSF Cyberlab investment accelerated both the pace at which research could be done, as well as the number of researchers and research projects that could be accommodated at any one time. In terms of student (graduate and undergraduate) education and professionals ongoing development, the Cyberlab created many opportunities to give students and professionals real world opportunities to collect and analyze video and more traditional survey data as part of authentic practice-based projects in a low stakes, low time commitment way and without all of them traveling to Newport on the rural Oregon Coast to spend time collecting data. Cyberlab collected data has been incorporated into and used for research methods and informal STEM research courses both on campus at Oregon State University and through OSU’s eCampus. The remaining data corpus (64 terrabytes of video data) can be made available to researchers anywhere in the world for a wide variety of uses from basic research to research training and, we believe, represents the largest corpus of informal STEM museum data ever collected. The use of the Cyberlab staff and equipment as both advisors to and components of multiple additional NSF, NOAA, and DOE projects attests to the value of the original investment in creating collaboration, education and innovation.

Conclusions

The NSF funded Cyberlab at OSU proved that off-the-shelf surveillance technology and hardware could be combined with tools of qualitative and quantitative analysis already familiar to learning sciences researchers to document and ultimately customize collaborative and individual learning in a public STEM museum learning setting. The project demonstrated that such data could be collected at both the individual exhibit (or visitor) level as well as the entire museum level, and that data collection could be done in such a way so as to take advantage of off-the-shelf tools for automating data flagging, reduction and some analysis without loosing the ability for a researcher to dive deeply into moment-to-moment interactions of individuals and collaborative groups. The Cyberlab (and its parent the FCL Lab) also demonstrated in that time the value of integrating large scale learning sciences research efforts into the daily operations of a museum in ways that benefit both research and practice. It finally established that the return on investment for research (and building capacity in the field for future research through education of students and professionals) of such a program is very high, but that the infrastructure and IT support costs are so high as to be out of the question for almost all public STEM venues. While because of these costs, the Cyberlab has been decommissioned from its full deployment, the project demonstrated that a mobile system could do achieve many of the same results at a fraction of the (long-term) expense. The trade off between a long-term research monitoring opportunity such as the fully deployed Cyberlab represented and the scaled-down opportunities offered by mobility remains to be documented.

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Rowe, S.M., Harwell, T., Preston, K., Sullivan, K., East, J., Rowe, S.R.M., & Farley, M. (Under review). End-Design Complexity as a Proxy for Engagement and Learning in Tinkering Exhibit Interactions

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Appendix A

Cyberlab Related Publications and Presentations

Barthel, C., Good, L., Rowe, S.M.,, & Stofer, K. (2014, March). Scientists, Educators, and Publics in Engagement: Who Learns From Whom in Science Communication, Education, and Outreach? Related paper set presented at the 87th Annual Meeting of NARST, Pittsburgh, PA.

Darr, K. (2019). The Deep Sea and Me: A Design-Based Research Study to Advance Public Literacy of the Deep Sea Using an Exhibit at a Public Marine Science Center. (Masters Thesis). https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/w3763d115?locale=en

East, J. (2015). An Exploratory Study on Family Group Use of a Multi-touch Table Exhibit at a Public Marine Science Center. (Masters Thesis). Retrieved from Oregon State University Scholars Archive https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/41687m987

East, J., & Rowe, S.M. (2019, March). Cyberlab. Presentation to the OSU Folk Club, Corvallis, OR.

Farley, M. (2018). Construction and Instructional Use of an Augmented Reality Sandbox. Northwest Managers of Educational Technology Conference. Corvallis, OR.

Farley, M. (2015). Race for the Museum X-Prize: Indoor Positioning Systems. Museums and the Web Conference, Chicago.

Farley, M. & Rowe, S.M. (2016, September). The Cyberlab: Free-Choice Learning Research. Invited presentation to MIT Sea Grant, Cambridge, MA.

Good, L. (2013). Unpacking docent practice in free choice science learning settings: A qualitative study documenting the what and whys of docent interpretive practice. (Doctoral Dissertation). Retrieved from Oregon State University Scholars Archive https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/1831cp37q

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O'Brien, S., Rowe, S.M.., Dierking, L, & Farley, M. (2014). Family Engagement in Live Animal Touch Tanks and Natural Tidepools: Links to Learning and Conservation Dialogue. *Proceedings of the 13th annual PCST meeting*, Salvador, Brazil.

Olds, S., Rowe, S.M.., Hanshumaker, W., Farley, M. (2014). Connecting the Public to Natural Hazards Through a Hands-on Museum Exhibit. *American Geophysical Union Fall Meeting Abstracts, 1*: 3906.

Rowe, S.M. (2012). Scientific visualizations as discourse nexus: Transmission of content or context for making meaning? In S. Norris (Ed.), *Multimodality in Practice: Investigating Theory-in Practice-through-Methodology* (pp. 50-65). New York: Routledge.

Rowe, S.M. (2012, August). Cyberlab: Data collection for large-scale, long-term multimodal analyses. A paper presented at the 6th International Conference on Multimodality, London.

Rowe, S.M. (2016, September). Learning with and from objects as mediational means and cultural tools. Invited keynote presentation at the Objects and Meaning Making in Museums Conference sponsored by RUCMUS and the Danish Center of Museum Research, Roskilde, Denmark.

Rowe, S.M. (2017, August). The Cyberlab: Innovation for learning research in multiple settings. Presentation to the HMSC Seminar Series, Newport, OR.

Rowe, S.M.., Farley, M., & Sullivan, K. (2016, February). Hatfield Marine Science Center Cyberlaboratory. Poster presented at the Biennial NSF AISL PI Meeting, Washington DC.

Rowe, S.M. & O'Brien, S. (2014, September). Museum learning research and Cyberlab: Goals, challenges, and results of building a new research platform. Invited presentation at the Divulgacao Cientifica e Museus de Ciencia meeting sponsored by the Red de

Popularización de la Ciencia y la Tecnología de América Latina y el Caribe, Rio de Janerio, Brazil.

Rowe, S.M., O'Brien, S., Farley, M., East, J., Good, L., & Stofer, K., (2016). Ciberlaboratório: usando observação humana e cibertecnologias para a pesquisa sobre aprendizagem por livre escolha. (Cyberlaboratory: Using Human Observation and Cyber Technologies for Research on Free-Choice Learning.) In L. Mssarani, R. Neves, & L. Amorim (Eds). *Divulgação científica e museus de ciência: O olhar do visitante - Memórias do evento*. (pp. 23-36). Rio de Janerio: Red de Popularización de la Ciencia y la Tecnología en América Latina y el Caribe – RedPOP & Museu da Vida / Casa de Oswaldo Cruz / Fiocruz. Available online at http://bit.ly/2bP28IF

Rowe, S.M, O'Brien, S., East, J., & Farley, M. (2014, August). Cyberlaboratory: Building Infrastructure, Knowledge and Capacity in Informal Science Education Research. Poster presented at the Biennial NSF AISL PI Meeting, Washington DC.

Rowe, S., O'Brien, S., Farley, M., & East, J. (2014). The Free-Choice Learning and Cyberlaboratory: Using Cutting-Edge Technology to Build Capacity at the Edge of Science and Science Communication. *Proceedings of the 13th annual PCST meeting*, Salvador, Brazil.

Rowe, S.M., Rowe, S.R., Sullivan, K.P. (2017, July). CyberLab Instrumentation for Innovative Learning Research in Multiple Scenarios. A panel presented at the 30th Annual Visitor Studies Association Conference, Columbus, OH.

Rowe, S.R.M., (2019). Are Families Talking about Conservation at Live Animal Exhibits? Analyzing Family and Professional Conservation Discourse. (Doctoral Dissertation). Retrieved from Oregon State University Scholars' Archive https://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/4q77fx046?locale=en

Rowe, S.R.M., Dierking, L., Farley, M., Rowe, S.M., Baker, H., & Sullivan, K. (2016, November). Family Engagement in Live Animal Touch-Tank Activities: A Reflective Discourse Analysis of Family Meaning Making and Conservation Talk. Poster presented at the Biennial Oregon Sea Grant Scholars Symposium, Corvallis, OR.

Appendix B

Mobile CyberLab Components and Cost Estimates (2018)

Item #	Product	Category	Amount	Cost	Subtotals
1	Cisco SG350-48MP	Switch	1	$ 916.00	
2	Dell PowerEdge r730 (with OS)	Server	2	$ 14,000.00	
3	WD Purple 6TB HDD (x)	Server	16	$ 2,224.00	
4	QNAP TS-463U-RP	NAS	1	$ 1,312.00	
5	WD Red 8TB HDD (4x)	NAS	4	$ 1,276.00	
6	CyberPower 1600 W UPS	UPS	2	$ 1,400.00	
47	Procool SP640TV	Cooling	4	$ 800.00	
7	Dell KVM Console	Console	1	$ 1,100.00	
8	15U Shockmount Case- 30" depth	Server case	1	$ 855.00	
		TOTAL			**$ 23,883.00**
9	Axis Q3505-VE 9mm (10x)	Cameras	15	$ 15,000.00	
10	Axis P3365	Cameras	10	$ 7,500.00	
11	ETS SMC-1 Mic/limiter (10x)	Audio	10	$ 700.00	
12	ETS SMM2 mixer (5x)	Audio	5	$ 250.00	
13	ETS SMM4 mixer (3x)	Audio	3	$ 200.00	
14	ETS ML1-C mic (5x)	Audio	5	$ 80.00	
15	POE splitter (4x)	Audio	4	$ 80.00	
		TOTAL			**$ 23,810.00**
16	Go Pro Hero5 Black	Camera	5	$ 2,000.00	
17	Lexar 633x Micro SD XC 200GB	Storage	8	$ 640.00	
18	GoPro Rechargeable battery	Accessories	5	$ 100.00	
19	GoPro Suction cup	Accessories	5	$ 200.00	
20	Go Pro Grab Bag	Accessories	2	$ 40.00	
21	GoPro Large tube mount	Accessories	2	$ 80.00	
22	GoPro Pole mount	Accessories	2	$ 60.00	
23	3.5 mm MIC adaptor	Accessories	3	$ 150.00	
24	tripod mount	Accessories	2	$ 40.00	

25	ball joint buckle	Accessories	5	$	100.00		
26	Sennheiser MKE 400 Shotgun Mic	Audio	5	$	1,000.00		
27	GoalZero Sherpa 50	Power	5	$	1,000.00		
28	GoalZero Boulder 30	Power	5	$	1,000.00		
29	Pelican Large Case 1730	Mobile	1	$	350.00		
		TOTAL				**$**	**6,760.00**
30	Dell Optiplex 7040 Micro PC	Computers	1	$	800.00		
31	Dell Latitude 15 5000 series	Computers	1	$	900.00		
32	Dell 22" Monitor E2216H	Computers	2	$	500.00		
33	Dell XPS 15	Computer	1	$	1,500.00		
34	Starcase OEMUTL	Additional Hardware	1	$	708.00		
		TOTAL				**$**	**4,408.00**
35	100' CAT6 cable (20x)	Additional Hardware	20	$	875.00		
36	50' CAT6E cable (10x)	Additional Hardware	10	$	150.00		
37	10' CAT6E cable (15x)	Additional Hardware	15	$ 50.00			
38	Bulk CAT6 Ethernet Cable	Additional Hardware	2	$	160.00		
39	RJ-45 Cable crimper	Additional Hardware	1	$ 20.00			
40	RJ-45 Crimp connectors	Additional Hardware	1	$ 20.00			
41	15ft rubber cable runner	Additional Hardware	2	$ 65.00			
48	Misc hardware (cables, wire, screws, etc)	Additional Hardware		$	200.00		
42	misc install tools (Drills, saws, etc)	Additional Hardware		$	250.00		
43	Starcase OEMUTL	Additional Hardware	1	$	708.00		
		TOTAL				**$**	**2,498.00**
44	**3VR SOFTWARE SUITE**	Software				$	18,450.00
	3VR VisionPoint VMS	Software	1	$	2,500.00		
	3VR Camera Licenses	Software	10	$	2,750.00		
	Advanced Object Licenses	Software	3	$	2,500.00		

	Facial Surveillance Licenses	Software	3	$ 2,500.00		
	Demographics Licenses	Software	3	$ 3,600.00		
	Loitering Licenses	Software	3	$ 3,600.00		
	Professional services support	Software	1	$ 1,000.00		
45	**MILESTONE SOFTWARE SUITE**	Software			$ 8,000.00
	Milestone Professional	Software	1	$ 500.00		
	Camera licenses	Software	15	$ 7,500.00		
	ADDITIONAL				$ 1,200.00
46	Adobe Premiere Pro	Software		$ 1,200.00		
		TOTAL			**$ 27,650.00**

Total Cost
$ 89,009.00

Mobile CyberLab Details

The server rack portion of the mobile CyberLab will be the central part of each "deployment." This unit is a duplication of the set-up located at HMSC, creating a hub for both a standard observation network, and an analytic-heavy system. The two Dell servers will host the two surveillance software suites (2, 3, 44, 45). This design also includes a Cisco switch (1) to create a local network for the servers, NAS, additional computers, cameras, and other devices to communicate. The Network Attached Storage (4 & 5) will serve as a location for general storage and exported footage. The KVM (7) allows users to switch between the different sources in the deployment. In addition to the server rack, there will be another container with additional workstations and supporting materials (30-33, 46) for data processing and user access to the systems. It also contains the IP cameras necessary for the two surveillance networks (9 & 10), and adjacent technology to make a robust and flexible observation system (11-15).

We also call for a "hardware" box; materials in here focus around the installation and ongoing maintenance of the mobile CyberLab. Network infrastructure materials (35-40) make up a good portion, allowing for a flexible deployment and easy setup/tear down. There also would be tools (42) for installation and maintenance, as well as a variety of hardware (41 & 48) to hang, hide, and/or protect the whole system.

Through our experience, there will always be rich study sites that has no technology infrastructure or ability to support any; in response, we have devised a "bare bones" version of the previously described system. This unit allows for the collection of A/V data in places without the capability of hosting the full server deployment, or for small discreet projects. It contains mobile cameras and storage capabilities (16-18), as well as a variety of installation methods to suit the location (19-22, 24, 25). There is also audio support (23 & 26), and outdoor or extended battery options (27 & 28)