Developing Interactive Exhibits with Scientists: Three Example Collaborations from the Life Sciences Collection at the Exploratorium

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Abstract

Science museums have made a concerted effort to work with researchers to incorporate current scientific findings and practices into informal learning opportunities for museum visitors. Many of these efforts have focused on creating opportunities and support for researchers to interact face-to-face with the public through, for example, speaker series, community forums, and engineering competitions. However, there are other means by which practicing scientists can find a voice on the museum floor - through the design and development of exhibits. Here we describe how researchers and museum professionals have worked together to create innovative exhibit experiences for an interactive science museum. For each example: scientist as (1) data providers, (2) advisors, and (3) co-developers, we highlight essential components for a successful partnership and pitfalls to avoid when collaborating on museum exhibits. Not many museums prototype and build their own exhibits like the Exploratorium. In those cases, there may be similar opportunities in more mediated offerings such as public demonstrations or lectures or in other formats that allow for direct interactions between scientists and visitors.

We believe there are many opportunities for researchers to share natural phenomena, to advise on exhibit development and interpretation, to provide much needed materials, and to otherwise incorporate authentic research into the learning experiences at museums, no matter what the format.

Keywords: informal learning, science museum, outreach, exhibits

Introduction

Exhibits are the heart of a museum experience. In a science museum or center, they "present natural phenomena, technological innovations and scientific ideas in ways that prompt visitors, interacting with them, to ask themselves questions and reinforce their own learning" (Semper 1990, pp 50). They may also focus on aspects of scientific practice, allowing visitors to engage in inquiry with the authentic tools and techniques a practicing scientist would use. A museum exhibit experience has been described as episodic versus continuous, short - possibly a few minutes, and unmediated, without staff facilitating its use (National Research Council 2009). Because museums are free-choice learning environments, visitors may not encounter, let alone choose to attend to an exhibit, and exhibits are rarely used according to a planned sequence. Some exhibits may be organized into an exhibition with a strong, overarching message; others may be placed in a loose thematic configuration with neighboring exhibits. Thus, there are no guarantees that a visitor will come to an exhibit with the prerequisite knowledge learned from a prior exhibit to make sense of the current exhibit being used (National Research Council 2009). Finally, the museum is a social and physical place (Falk and Dierking 2012), where visitors come with family and friends to, increasingly, use hands-on interactive exhibits.

Although all museums curate their exhibit collections to fit with their mission, audience, and institutional priorities, not all museums are able or choose to develop their own exhibits. The three examples given in this paper are illustrations of what is possible when there is a development team at an institution, the Exploratorium, with a long history and commitment to prototyping. Museums without in-house exhibit development staff can use these examples to guide their relationships with local researchers, inform their work with outside consultants, and as inspiration to create their own exhibits and programs with researchers. Each example represents a different way in which research scientists worked with exhibit developers under multiple constraints to create an engaging exhibit for the museum floor: (1) researchers as data providers, (2) researchers as advisors, and (3) researchers as co-developers.

Background

Biology Exhibits at the Exploratorium

The Exploratorium, founded in 1969 by Frank Oppenheimer, is an organization dedicated to creating inquiry-based experiences that foster curiosity about the natural world. The museum is located on the San Francisco waterfront where we create tools and experiences for our museum visitors, our online audience, local communities, teachers and other educators, and museum professionals. The public floor of our museum has over 600 exhibits in seven galleries loosely organized by subject matter. Many of these exhibits are interactive and almost all of them were built on-site in the Exploratorium's machine shop.

In addition to the machine shop, the Exploratorium has an on-site 3,000 square-foot biology laboratory. The laboratory facilities include a sterile cell-culturing room, -80^{o}C freezer, incubators, an autoclave, fume hood, lab benches, and safety equipment. It also houses dedicated plant-growing facilities, a zebrafish culturing facility, and a salt water table. The laboratory contains numerous dissecting and compound microscopes, including four research-grade automated microscopes in the Microscope Imaging Station facility. Staffed by biologists, the laboratory cares for a living collection of over 40 types of samples, including fruit flies, human stem cells, mimosa plants, and an assortment of microbes. This facility is adjacent to the exhibit floor and is used to support new exhibit development and ongoing exhibit maintenance.

The following outlines the basic process used to develop biology exhibits at the Exploratorium (Fig. 1), with a focus on what may be helpful to potential scientific partners who wish to become involved.

1. Discover and understand the phenomenon. The first step to developing an exhibit is to identify a compelling phenomenon with which visitors can interact. Ideas can come from various places including research papers, classroom demonstrations, Internet searches, and art installations. Academic conferences offer a wide array of talks in a defined content area, as well as a way to meet researchers in person. Museum staff may not be members of multiple academic societies so access may be an issue. To bridge that gap, researchers can sponsor museum staff from their local institutions to attend a conference in a subject area they are currently exploring. Another very important way we identify candidate phenomenon is through visiting research laboratories. Lab visits allow us to see new phenomena and organisms, as well as the equipment necessary to maintain and interact with them. Inviting museum staff into research labs is a low stakes way scientists can support our work.

   While searching for potential exhibit ideas, we constantly assess how well a potentially interesting phenomenon might translate to an exhibit. We ask hard questions prior to the start of prototyping and often depend on scientists to help us better understand the answers:

   - Is an exhibit the correct outcome for the phenomenon, content, and concepts? Many concepts and content areas are very difficult to adapt to hands-on, phenomenological exhibits. If an idea is not well suited for a phenomenon-based exhibit, it is best to acknowledge this early and explore other options. Perhaps a live demonstration by a knowledgeable scientist would be more engaging to visitors or spark another exhibit idea?

- Is the interactivity of the proposed exhibit meaningful to visitors? Can visitors interact with the phenomenon, or is the interactivity solely designed to deliver more content or give the visitor something to do divorced from the actual phenomenon? Do visitors even understand that they are interacting with the phenomenon? This is a question that may best be answered by talking with visitors to ascertain their point of view.
- Can visitors experience the phenomenon? Is the phenomenon reproducible and at what time scale? Because many Exploratorium visitors spend less than 30 seconds at an individual exhibit, it is important for the phenomenon to be readily experienced upon approach.
- Is the exhibit experience worth the development effort and cost? For example, is the technology needed for the exhibit stable and affordable? Would this be the case in five years?
- If an exhibit successfully makes it to the museum floor, can it be maintained? Is there a local laboratory that is willing to support the exhibit with raw materials for the long term?

The length of time for this phase of a project can vary widely from 2 months for a single exhibit, to a year or more for groups of exhibits. Content that is more abstract, goals of funders and museum staff, and technical complexity can add time to this estimate. The best strategy is to discover more ideas than the number of eventual exhibits. Smaller museums may want to focus on developing fewer interactives which are supported with more traditional exhibitry.

2. <u>Prototype</u>. Once these questions have been initially assessed, and we believe the idea is worth pursuing, we follow an iterative development process informed by visitor evaluation. We

continue to ask these questions especially during the early stages of prototyping. At first, exhibit developers try out simple, mocked-up, mediated interactions to explore the phenomenon. If these initial interactions show potential, the exhibit developer does a deeper dive to develop her understanding of the phenomenon, often with scientists' help, and to determine ways to exhibit the phenomenon. Typically there are several rounds of quick, low-cost prototyping with small groups of colleagues before it is tested with visitors for refinement.

3. Evaluate with Visitors. Once the exhibit developer has a prototype that she feels is ready for visitor testing, she starts a conversation with an evaluator to determine what type of visitor input would be useful and can be collected to inform the prototyping process. Evaluation is an integral part of exhibit development at the Exploratorium, used to understand visitors' interactions with a prototype and identify potential issues and opportunities for improvement. Evaluation can help refine an early prototype as well as check a fully functioning version of a nearly complete exhibit before its final build. The Exploratorium's Visitor Research and Evaluation Department works closely with developers throughout the prototyping effort. Not all museums have in-house evaluators and may depend on outside consultants or other staff members. What is important is that usability issues and misinterpretations are identified and addressed and that often depends on talking and/or observing visitors systematically with the prototype.

   Timing of prototyping and evaluation varies greatly depending on the complexity of the exhibit, both in terms of content and interactivity design. It is important to remember to keep the exhibit as simple as possible. Avoid incorporating multiple ideas and pathways in to a single design (Allen and Gutwill 2004). Expect to budget 3-4 months for a single exhibit, up to a year for more technically complex exhibits like Example 3 described below. Smaller museums may want to work with local fabrication shops to assist in prototyping.

4. Design and build. After multiple iterations, the exhibit developer converges on the final interaction design. The central focus of the design phase is to keep the interaction true to the prototypical form, while hardening the design so it can withstand the rigors of the museum floor. The exhibit components are often drawn and assembled in 3D modelling software so the vision of the exhibit developer can be shared with the project team. The design takes into account ADA guidelines, durability of materials, and standard components that have been used successfully in previous exhibits. Often, designs and components with proven durability become standards that are applied to future exhibits. If the exhibit is part of a larger collection, design elements and materials may be shared among several exhibits. In our experience, we expect to budget up to four months per exhibit for design drawings, fabrication and assembly. If working with outside fabrication shops, it may be best to bundle multiple exhibits into batches. Smaller museums can develop relationships with local workshops that may provide design help, or work with an exhibition design firm during the production phase of the project.
5. Document. Once an exhibit is successfully installed and can be maintained on the museum floor, it is extensively documented and archived for future reference. Documentation can include pictures of early prototypes, fabrication drawings, background information on the scientific concepts in the exhibit, and a contact list of vendors and/or research scientists who have provided materials. Document early and often, and complete the documentation package within two months of the opening of the exhibition while the information is still fresh.

6. Maintain and Improve. At the Exploratorium, we like to think that no exhibit is ever truly "finished". Instead, we feel that most exhibits can be improved over time, as we learn more about visitors' interactions, with the evolution of technology, or with scientific advancement. However, limits on time and resources mean that revisions become few and far between as time passes and the focus shifts to exhibit upkeep. It is important to clearly communicate when the exhibit development project is complete and the commitment of the scientist is fulfilled. If the exhibit needs ongoing support such as live cultures, these should be clear and agreed to by the researchers and museum staff.

Example 1: Researchers as data providers

The following example from the development of the exhibit, *A Cell in Motion*, illustrates how researchers can share scientific data for exhibits.

1.1 Exhibit Description

A Cell in Motion is a large, mechanical zoetrope that features 3D prints of a real cell crawling across a surface, imaged at the University of California, San Francisco (UCSF). A zoetrope is an 18th century device that creates an illusion of motion using a series of still images, or in this case 3D "sculptures." Recent advances in microscopy have made it possible to capture 3D images of live cells, which we were then able to 3D print using the original data. *A Cell in Motion* has 49 cell sculptures, each approximately 3.5 inches in length, representing about two minutes of the cell in motion. As a visitor turns a hand crank, strobes flash in time with the speed that the cells pass by, creating the illusion that a single cell is moving in three dimensions (Fig. 2A and 2B).

1.2 Components of a successful data share

Megan Riel-Mehan, a postdoctoral scholar in UCSF's Department of Bioengineering, serendipitously met an Exploratorium biologist at an academic conference and showed her a zoetrope movie she made using 3D data from the light sheet microscopy work of Dr. Lillian K Fritz-Laylin from the Department of Cellular and Molecular Pharmacology at UCSF. The Exploratorium biologist shared the movie with an exhibit developer, who was inspired to make a physical version, envisioning the cells rendered as physical objects in a series. Dr. Riel-Mehan worked with the exhibit developer to optimize her data for the museum's 3D printer and to choose an appropriate sequence of images that would be printable at the Exploratorium. The key ingredients to this successful collaboration were Dr. Riel-Mehan's willingness to share her data visualization expertise and her data, which required a degree of trust since the scientific data had yet to be published when prototyping work began. The findings have since been published (Fritz-Laylin et al. 2017), and the contributions of the scientists are revealed to visitors in the exhibit label. All data sharing and communications were electronic, making this type of relationship amenable to geographically distant groups.

Example 2: Researchers as advisors

The example of the Microscope Imaging Station (MIS) project lets us look at the participation of the scientific community over the course of a multi-year project that focused initially on exhibit development but has evolved into an important programmatic cornerstone of the museum's biology collection.

2.1 Project Description

The MIS project started with the goal of bringing the beauty and wonder of live microscopic samples to museum audiences. With developments in automated microscopy, it had become feasible to adapt research-grade, computer-controlled light microscopes for use by museum visitors. Previously, the use of such instruments had been primarily limited to academic laboratories at universities and other research institutions. The initial project proposal was developed by the Exploratorium in collaboration with a research scientist with a significant background and experience in microscopy, as well as a desire to reach the public with the imagery and sense of discovery that he found so compelling in his scientific work.

Housed in a room with large windows onto the exhibition floor, the MIS facility contains four automated, computer controlled light microscopes. There are currently three Zeiss MZFLIII inverted microscopes and one Zeiss AxioZoom, all with computer controlled stages, focus, objective change (or, in the case of the AxioZoom, a zoom), and light settings. On the outside of the facility, on the museum's public floor, are kiosks that enable museum visitors to "drive" the microscopes and look at a live, full color video direct from a microscope on a large screen. Visitors control the microscopes using a joystick to move the motorized stage, a knob to focus, and a touchscreen, where virtual buttons let visitors choose magnification, light conditions and sample type. The microscope used by a visitor is in view through large windows, and the live image from the microscope also appears above the window on a large video monitor (Fig. 2E). All samples featured in the MIS exhibits are alive, and may include developing zebrafish (*Danio rerio*) embryos, the protist *amoeba,* mouse embryonic stem cells, or cardiac myocytes derived from mouse embryonic stem cells. Adjacent to the live image, interpretive media guides visitors through sample exploration and provides context and information about the live sample in view.

2.2 Components of a successful advisory relationship

Advice from the research community was particularly valuable during the initial stage to help staff discover and understand the phenomenon and technology. This advice came in several forms:

Equipment Expertise. During the initial phases of MIS development, choosing what hardware to invest in was critical. The advice and expertise of a number of project advisors were invaluable in pointing the museum team toward instruments that they as researchers and everyday users could recommend in terms of robustness and meeting the technical needs of the project. They also could speak from direct experience using these microscopes about ease of use and extensibility to studying a wide variety of live samples. The choice of key accessories for the microscopes such as heaters, objectives, video cameras and shutters were also heavily influenced by the perspective of the project's research advisors.

Sample Selection. Critical to the success of the 'exhibit' aspect of the project and visitor engagement, was sample choice and procurement. For this, the museum project team had the benefit of being in San Francisco. With a number of research universities as neighbors, proximity was key, enabling museum staff to visit a number of laboratories in search of suitable live samples for this suite of microscope exhibits. A number of researchers in the San Francisco Bay Area generously hosted visits so that the MIS project team could not only see the live samples in action in a scientific setting but could also have honest conversations with the scientists using the samples as to how feasible it might be to maintain the sample in the Exploratorium's laboratory. Once appropriate samples were identified, researchers were enormously generous in providing these live specimens to the museum to be used in the exhibit, or providing detailed information about where to obtain the samples and how to maintain them.

Scientific Content and Practice. Finally, with the instruments in place and live samples chosen, scientific advisors were asked about how they used the live samples in their basic research. These stories and in-depth scientific discussions became the backbone of the interpretive media that accompanies each live sample in the exhibit.

Example 3: Researchers as co-developers

The Visitors Interactions in Microbiology (VIM) project is a partnership between the Exploratorium and the Riedel-Kruse Bio-engineering Laboratory at Stanford University, which has pioneered hybrid digital-biological systems that allow users to manipulate microbial behavior. Both parties are co-leads and are co-developing the VIM exhibit prototypes. As such, of the three examples described in this paper, this represents the highest level of commitment and integration from participating scientists.

3.1 Project Description

The VIM project aims to shed light on how biotechnology can be integrated into exhibits to allow real-time interactions with microscopic life at the human scale. Exploratorium staff and researchers from the Riedel-Kruse Lab met serendipitously during an academic conference. At the time, the Riedel-Kruse Lab had already built a prototype system, *Trap it!* , that allows museum visitors to draw images on a touchscreen, which are projected onto a microscope slide with live organisms, *Euglena gracilis*. These microbes are phototatic and, therefore, respond to the images projected from the human-scaled world. The microbes and the light drawing on the slide are, in turn, projected back to the touchscreen. An evaluation conducted on *Trap it!* indicated the possibilities of this system as a promising platform to introduce interactivity into biology exhibits (Lee et al. 2015). Since our chance meeting, the Exploratorium and the Riedel-Kruse Lab have worked together to adapt the original platform to create a physical, multi-user interactive experience for visitors (Fig. 2C and 2D).

3.2 Components of a successful co-development partnership

Agenda Alignment. This co-development effort reflected a fortuitous alignment of the Exploratorium's and the Riedel-Kruse Lab's agendas. As a museum known for its hands-on exhibits, the Exploratorium is always looking for ways to create engaging, interactive experiences for its visitors. Interactivity in biology exhibits has been traditionally realized by providing observational instruments such as webcams or microscopes for visitor control, or hands-on models or computer simulations for manipulation. The biotechnology system prototyped by the Riedel-Kruse Lab offered a novel means of introducing a new form of interactivity into the repertoire of science exhibits in microbiology not just for the Exploratorium but for the larger museum field. At the same time, the Riedel-Kruse Lab had prototyped and evaluated its *Trap it!* platform and was beginning to look for other opportunities to adapt and use their system in informal learning environments. Working with the Exploratorium on a co-development project offered a means of using and refining their bioengineering work for learners in museums.

Complementary Expertise. The Riedel-Kruse Lab brought deep expertise to the design and development of the biotechnology system used for VIM, while the Exploratorium staff has decades of experience building, prototyping, evaluating and maintaining interactive science exhibits. Nonetheless, everyone on the VIM project learned enough about the prototype, the enabling platform, and the visitor experience to work together to strategize next steps, make informed decisions, tweak the experience when necessary, and keep the prototype running during critical stages of testing.

Each party's expertise was brought to the fore at different stages of the exhibit development process:

1. <u>Discover and Understand the Phenomenon</u>. The Riedel-Kruse Lab has extensive experience working with *Euglena* and knew the minute details of their phototactic response to different light wavelengths and intensity as well as their upkeep. The Exploratorium staff had less

extensive knowledge but learned through working with the research scientists to recognize the different microbial reactions to different lighting conditions, generate early ideas for visitor interactions, and ways to maintain samples at the Exploratorium that would reliably respond to stimulus.

2. <u>Prototype</u>. The Riedel-Kruse Lab designed and developed the biotechnology platform and therefore knew not only how the platform worked and could be adapted but the history of what had been tried and why a particular solution may or may not work. Throughout the co-development effort, they held the deep expertise on the biotechnology platform, and as such, drove the redesign of the system. This included making design decisions, securing parts and putting together multiple versions of the prototype.

   Meanwhile, multimedia exhibit developers at the Exploratorium brought their expertise in using existing and emerging technologies in exhibit development and public installations to the prototyping effort, taking the lead in the design and development of the Kinect-based user interface and projection displays. The tight integration between the platform and the user interface required very close collaboration between the Riedel-Kruse Lab and the Exploratorium, with clear understanding of the two subsystems' interface.

3. <u>Evaluation with Visitors</u>. For the VIM Project, evaluation ranged from informal observations done by Riedel-Kruse researchers and Exploratorium developers, to more formal studies with visitors conducted by Exploratorium evaluators. Through a cycle of prototyping and evaluation, the VIM team built a shared understanding of how the VIM exhibit would work with visitors in the museum setting, grounded in the Exploratorium's past experience with exhibits, refined by technical testing of the VIM prototypes on the museum floor, and informed by visitor reaction and feedback. For example, the iterative process led us to select

an eyepiece that could accommodate children who tend to have difficulties positioning themselves to see through the oculus. The light stimulus was carefully calibrated to effect a response from the Euglena that was meaningful to visitors who do not have the experience to readily recognize evasive behavior. And, the system was redesigned to address situations where continuous use by visitors drove away all the Euglena from the active field of view.

Onsite Work. One critical aspect of co-development was the need to do some of the prototyping onsite. It was not the case that the researchers could build the prototype in their lab and install it on the museum floor. This was especially true for a system that needed to be fine-tuned to the light levels, the environmental conditions, and visitors' creative and frequent interactions. We also learned that given the complexity of the system, even trained staff at the Exploratorium could not easily step in and debug the system should something fail. Having a science partner that was in close proximity made rapid prototyping and debugging possible. Even so, we found it helpful to develop a system that allowed the researchers to remotely control the prototype and processes by which data from the physical prototype could be automatically recorded and transferred at the end of the day to the research lab for closer analysis to assess calibration levels.

Ongoing work. The VIM project is a work in progress with evaluation, design and build, documentation, maintenance, and improvement, still ongoing. The goal is to work out the prototype's technical issues with the Riedel-Kruse researchers, determine the best-case use scenarios for visitors, then proceed to the design and build phase with the Exploratorium taking the lead.

Conclusion

This paper describes several ways in which research scientists have participated in the exhibit development process at the Exploratorium including: hosting laboratory site visits, providing materials (e.g., reagents, data, software, specimens), advising on scientific content and technology, co-developing exhibits and technology platforms, and co-writing exhibit development proposals. Although different types of participation require different levels of time and resource commitment, we have found it useful for both parties to consider the following before agreeing to work together:

- Do the parties' agendas align? At the very least, do the scientists believe they are contributing to something worthwhile at the museum and that their participation is meaningful? Sometimes exhibit prototypes fail and need to be abandoned. Is this an acceptable outcome for the researchers? Alternatively, does the work proposed fit with the timeline and institutional priorities at the museum?
- Is there a shared understanding of roles and responsibilities? And, can all parties commit the time and resources required? People outside of the museum field are often shocked at the time and money involved in taking an idea to a fully functioning museum exhibit. Are both parties clear on the process, what is expected of them and realistic about what they can bring to the effort?
- Are both parties dedicated to cultivating a long-term relationship? In any collaboration especially between very different professional cultures, both groups need time to establish a common language and learn to communicate with each other. We have often found that thinking of a collaboration, no matter how short, as part of establishing and maintaining a long-term relationship helps both parties invest in not just the project but in each other and makes working together easy and fruitful, sometimes leading to additional opportunities.

Not many museums prototype and build their own exhibits like the Exploratorium. In those cases, there may be similar opportunities in more mediated offerings such as public demonstrations or lectures or in other formats that allow for direct interactions between scientists and visitors. For example, during *Scientists at Work* days at the Exploratorium, biologists are invited to set up, as they usually would in their own laboratories, in an open-air laboratory space adjacent to the Living Systems laboratory facilities inside the museum, and carry out their experiments for visitors to witness (Fig. 2F). They do not give a scripted demonstration but instead conduct authentic research in public view. Low, glass panels between the lab bench and the museum floor allow for the scientists to stop and have conversations about their work with interested visitors. Signage, produced in collaboration with museum staff, is used to attract visitors, but text is kept to a minimum to simply highlight the big picture goals of the research, and to depict the logos of the research organizations. We hope that *Scientist at Work* days not only provide the public insight into the authentic practice of science but offer scientists and visitors a means to interact in personalized and meaningful ways. These interactions often allow for the researchers to share their personal stories about their science careers, and help to humanize the practice of science for our audiences. For more information on forming partnerships between researchers and informal science learning centers, we recommend Carol Lynn Alpert's *A Guide to Building Partnerships between Science Museums and University-Based Research Centers* (Alpert. 2013).

We believe there are many opportunities for researchers to share natural phenomena, to advise on exhibit development and interpretation, to provide much needed materials, and to otherwise incorporate authentic research into the learning experiences at museums, no matter what the format.

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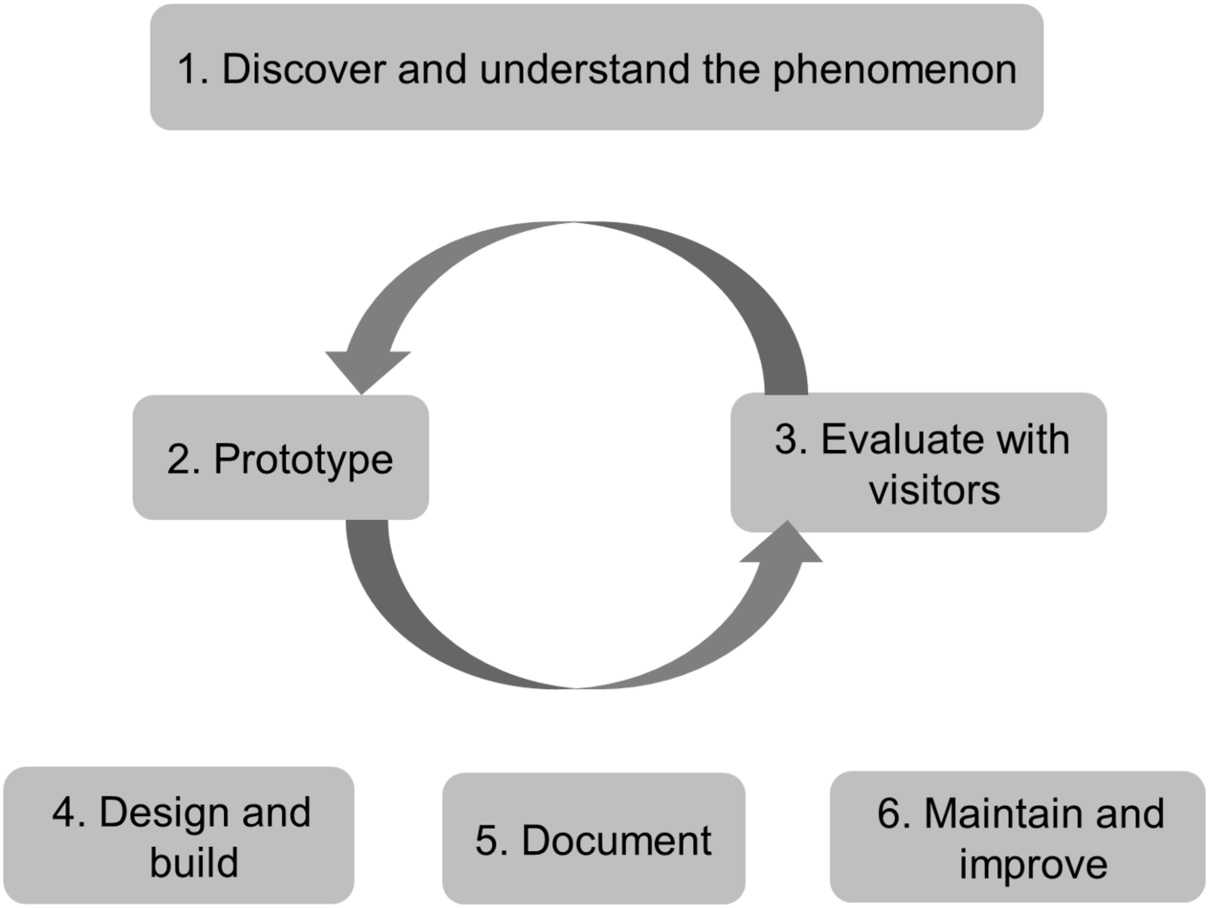

Fig. 1- Exhibit development process.

Fig. 2- Exhibit Prototypes and Facilities. A) *A Cell in Motion* exhibit. B) *A Cell in Motion*'s 3D sculptures. C) Two people using the VIM exhibit prototype. D) The large projection and the microscope in the VIM setup.E) Visitors using the interactive microscopes in MIS. F) *Scientists at Work* with visitors at the Living Systems laboratory facilities.