IPS Project, Final Report
Expert Evaluation Consultant Review
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**BACKGROUND:**
In late 2013, the Exploratorium (PI Joshua Gutwill, Co-PIs Joyce Ma and William Meyer) received a two-year NSF EAGER grant for *An Indoor Positioning System for Informal Learning Experiences*. (A third year was added as a no-cost extension.) In this project, the Exploratorium, working with an industry partner, Qualcomm, completed foundational research and development on an indoor positioning system (IPS) and associated applications (audio and database) in order to improve museum experiences for visitors as well as to improve the capacity of museums to study learning within museums.

Specifically, the project question was: How can museums appropriately track visitors within indoor venues in order to understand and improve their STEM learning experience? Despite extensive discussion and trial implementation within the field, there are no industry standards in terms of a hardware approach (WiFi, video, etc.) or software standards. Museum indoor tracking apps heralded at conferences produce inconsistent results when actually tested. Part of the impetus for this project was to establish learning as a focus of tracking capacity, and not merely as a secondary component of marketing-focused technologies.

**The overall project objectives:**
(1) Design, develop and test a whole-museum Indoor Positioning System (IPS), at three levels of resolution: gallery, exhibit cluster, and exhibit.
(2) Prototype a research data management system, i.e., develop and validate IPS-based methods for collecting and processing timing and tracking data for visitor research.
(3) Develop processes for creating and updating indoor maps at each resolution level.
(4) Test an IPS as a tool for program development and delivery.
(5) Disseminate project findings, including tools and techniques developed for analyzing location data.

The Exploratorium team asked that I complete the external advisory review for this project, through my company, Haley Goldman Consulting. I am a researcher and evaluator with expertise in the implementation of innovative museum technology and visitor outcomes from using that technology. My overall role on this project has been to provide a critical, reflective review of the progress of the project. This review is based on a review of the materials produced throughout the project, the evidence presented at professional conferences, documentation provided, and discussions with the Principal Investigators and team.

I have approached this review in a two-step process. The first step was to come to consensus on whether the progress on this activity was appropriate; the second was to critically consider the work in terms of rigor, depth, and similar scholarly concerns.

The project is now at the conclusion of the grant period. The team has completed the stated objectives, and this report will review and discuss progress on each.

**Objective 1: Design, develop, and test a whole-museum Indoor Positioning System (IPS), at three levels of resolution: gallery, exhibit cluster, and exhibit.**

This objective was achieved, although testing revealed gallery level and exhibit cluster resolution to be mostly stable, and exhibit-level resolution is not yet achievable. These findings from the research in pursuit of exhibit-level resolution are invaluable to the field, as despite intensive and rigorous testing, the team was unable to get exhibit-level positioning information. Individuals using devices could be reliably tracked to a gallery, or even a particular area of a gallery, but the technology the team was working with could not distinguish specifically when a visitor was at a particular exhibit. This finding influenced the rest of the course of the project, and some of the other objectives in each year. It should be said that if this technology could produce exhibit level resolution with the technology available currently, the Exploratorium team would have achieved this objective, as their work has been careful and considered in this regard.

The objective of attaining exhibit-level resolution was not achieved, however highly desirable data and lessons have been gathered from the work to date. As detailed in the Exploratorium team's report, the team designed and tested a WiFi-based IPS within the museum, with 65 WiFi access points and 8 mobile test devices. In my opinion, the tests were carried out with extensive thought given to each variable, and an exceptionally high degree of rigor. The specific findings on the accuracy of the tracking system are notable. By defining the boundaries of a gallery and determining whether a person being tracked is inside of the gallery or not, one can start to understand where the "real" boundaries are. The visualization of the tracking was quite impressive, in intuitiveness and ability to show how a person moved through the galleries. It is particularly useful to know to what extent the line tracks actual movement; meaning, what is the range to either side of the line compared to the actual movement through the gallery. Having a prescribed path to test the ability of the device to accurately track where a person is going, and having a human counterpart to test the device is invaluable information.

This finding (i.e., exhibit-level resolution would not be achievable during the life of this grant) created a pivot point for the team. To help understand their next steps, I would first like to reiterate some background on the issue of indoor positioning.

**BACKGROUND ON INDOOR POSITIONING:**
The Exploratorium team tackled one of the current unsolved challenges within the museum technology field. Global Positioning Systems (GPS) technology has inspired thousands of usages beyond the originally envisioned military applications, just as the internet has inspired millions more. GPS functionality supports many everyday museum visitor functions, from locating and providing directions to the museum, to looking at prior visitor Instagram photos of the same location. Visitor (and staff) expectations are built on the concept that institutions, items, and even people can be located in real time.

Yet GPS does not function well within the museum space. Cell reception is often poor due to a combination of thick walls, metal, and unshielded electronics. Thus while our colleagues in zoos and outdoor historical sites can offer GPS-based interpretation and activities, indoor institutions have not been able to do so. Yet many institutions are highly interested in being able to track visitors through their institution. In this project, the Exploratorium team hoped to gain visitor evaluation data, while other institutions are also looking forward to the potential advances in understanding visitor flow and ticketing, maintenance of interactives, marketing of additional offerings and programs, and not least, engaging visitors in deep interaction in the components of the institution they are actually using.

Since to a great degree GPS is unavailable, museums are taking several different strategies to tackle indoor positioning. This is a hot topic for many museums, and I regularly hear of institutions trying to implement such systems, with few to no reports of functioning systems.

Currently, those strategies are in the following three areas:

**Strategy 1) Signal triangulation:** The museum sets up a series of broadcasts, typically WiFi-based, that a phone app would use to identify location and send it back to a central server. This requires no effort from the visitor, other than downloading the app, or wearing a mobile phone provided by the museum with a tracking app, but triangulation can be expensive and requires significant infrastructure investment. This is the strategy the Exploratorium team has taken, more on this later in this review.

The first viable system I'm aware of is also built on WiFi access points, the Explorer App from the American Museum of Natural History, released in 2010. Primarily a wayfinding app for their the highly complex building, this installation required over 300 access points and reportedly over a million dollars to fund. Indoor positioning via WiFi was also the backbone of the ArtLens app developed at Cleveland Museum of Art in conjunction with their Gallery One initiative. The overall initiative cost $10 million; it is unknown how much of that cost was for the WiFi access points, installation and the app. A second version of the Explorer app is currently under evaluation, with initial reports that visitors find the wayfinding to be mostly accurate and quite useful.

**Strategy 2) Item ID:** The visitor uses their phone to scan or trigger something within the exhibit. Typical technologies might be QR-Codes, RFID tags, Augmented Reality triggers, or image recognition. For this strategy, the visitor needs to actively interact with an item. The installation here is easier and less expensive, as triangulation is not required, but development of each "kiosk" or other touch point requires development effort. Getting visitors to use the system can be a challenge, and uptake rates vary widely.

Variants of this system are used widely across museums, from image recognition using the ArtClix app at the High Museum of Art, to RFID tag scanning at Bill Nye's Science Lab at the Chabot Space and Science Center, to the visitor "pen" that is given out at the renovated Cooper Hewitt Museum in New York.

**Strategy 3) Zone identification:** Typically done with low energy Bluetooth signals, this strategy allows the visitor to be passive, as the technology send out small, localized signals that tell you which "zone" the visitor is in. This strategy encompasses technology such as Apple's iBeacons. This system is also cheaper to install (though it also might require many access points), and requires development effort. For instance the Canadian Museum of Human Rights uses low energy Bluetooth via several hundred Estimote beacons as part of their Universal Design strategy. This solution allows for their accessibility layer to work at the gallery level.

Other strategies include camera-based tracking and geofencing. Camera-based visitor tracking is under extensive research by Shawn Rowe and Mark Farley at Hatfield Marine Science Visitor Center at Oregon State University, but currently the cost and the number of cameras makes this impractical for most institutions.

At the end of the first year, after extensive prototyping and testing and conversations with its technology partner, Qualcomm, the IPS project determined that WiFi-based signal triangulation would not provide exhibit-level resolution in the coming years, and pivoted towards testing Bluetooth Low Energy (BLE) beacons as a potential solution. The team conducted tests focused on assessing BLE beacons at exhibit-level resolution.

In these tests, GeLo beacons were mounted on 8 different exhibits in a small (3500 sq ft) gallery of approximately 24 exhibits. A human tester then walked the gallery wearing four BLE mobile devices around her waist, on the front, right, back, and left of her body. She stood at each use spot for each exhibit for 30 seconds, and then stepped away, noting the time. A logging app installed on each mobile device recorded the signal strength from which exhibit location would be calculated. The tests indicated that this alternative BLE beacon system could not distinguish the signal received at one exhibit versus its neighbors. That is, it could not provide exhibit-level resolution.

I concur with the team's conclusion from their report: "Because resolution can vary within a gallery depending on the physical placement of the APs, the geometry of the space, and electromagnetic events, we recommend that the installation of any IPS include extensive testing to assess adequate resolution."

**Objective 2: Develop a research data management system, along with tools for the field for the analysis and interpretation of data**

This objective was achieved, providing useful tools to the field for professionals who wish to interpret movement through galleries. The work towards this objective was designed and executed with a high degree of rigor. The team created TrackR, a collection of example scripts and supporting functions written to facilitate 1) the validation and 2) the analysis of timing and tracking data collected for research and evaluation in the visitor studies field. In this, the Exploratorium made use of R, a free statistical program growing greatly in use among both statisticians and data graphics professionals. As R is rapidly becoming a preeminent program for analysis, developing the visitation pattern system in R means that other institutions, even those not using the same hardware or strategy for indoor positioning, may be able to use this system for back-end interpretation of the data. The team was able to convert the longitude/latitude location and time data outputted by the IPS into meaningful metrics (e.g., dwell time, gallery visited, sequence of gallery visited, differences between sequences, visitation patterns) and visualizations. In particular, the visit segmentation analysis tools in TrackR are highly useful for other institutions seeking understanding of visitor decision-making of path. The protocol and supporting tools for doing ground-truthing and analysis of IPS data are available free of charge to other institutions through a bitbucket repository.

**Objective 3: Develop processes for creating and updating indoor maps at each resolution level**

Progress towards this objective was made. This objective could not be fully achieved due to the difficulties in creating a stable and viable indoor positioning system at the exhibit level. However, the exhibit level test protocol defined in this project can serve as the basis for a method for generating an indoor map of exhibit locations using an IPS. This method uses ground truth data to calculate centroids from which a Dirichlet tessellation pattern can be generated. The tessellation tiles effectively define the boundaries, or footprint, of each exhibit relative to the Wi-Fi APs and thus places each exhibit on an IPS map. However, because the Exploratorium IPS did not provide exhibit level resolution, this method could not be validated.

**Objective 4: Test an IPS as a tool for program development and delivery.**

This objective was completed through the testing of the Roundware app as a location aware content delivery system.

The Exploratorium team employed software platform called Roundware, developed by media artist Halsey Burgund for crowd-sourced audio and comments at exhibits based on indoor positioning triggers. Visitors can listen to content based on their location, or contribute comments of their own. Roundware was used in the Exploratorium's Observatory Gallery, a small exhibit space of approximately 3,500 feet focused on the local bay environment. The app, available via loaned device from the museum, was seeded with a few dozen remarks from visitors, staff, artists and scientist, each lasting no more than 30 seconds. Many of these remarks pertained to a specific exhibit, but some were about the gallery itself or about the outside landscape visible through the windows of the Observatory.

Generally speaking, visitors mostly listened to the content without contributing their own. They found the experience pleasurable, as they could listen to the comments of others. While prior reports point to the potential of these Roundware apps to encourage visitors to pay closer attention to the art they encounter, this finding was not replicated within the Exploratorium test. Visitors did not have a longer stay time or visit more elements of the exhibition.

The app provided cluster-level resolution rather than exhibit-level resolution, and as such over two-thirds of the visitors interviewed reported feeling frustrated and/or confused by the mismatches between what they heard and their exhibit experience.

The evaluation was rigorous in deducing and reporting mismatches in audio content and visitor location, and thoroughly examined visitor feedback on experiences with the app. This work demonstrated potential conditions under which this format might be successful in the future.

**Objective 5: Disseminate project findings, including tools and techniques developed for analyzing location data collected.**

As mentioned above, the tools and protocols for ground-truthing and analysis of IPS data were made available free of charge to other institutions through a bitbucket repository (https://bitbucket.org/account/user/exploratorium/projects/IPS).
In addition, the team at Exploratorium has disseminated the results both formally through the papers and presentations below, and informally through discussions with colleagues. These conversations have supported other ISE institutions including the Franklin Institute, the Monterey Aquarium, and the Saint Louis Science Center, who were considering investing money and time in a similar system.

Poster Presentation: Ma, J., Gutwill, J., & Meyer, W. (2014, August). EAGER: An Indoor Positioning System (IPS) for Informal Learning Experiences. Poster presented at the NSF AISL PI Meeting 2014, Washington D.C.

Panel Presentation: Haley Goldman, K., Thistlewolf, D., Wyman, B., Farley, M. & Chan, S. (2014, April). Race for the Museum XPrize: Indoor Position Systems. Presentation at the Museums and the Web Conference 2015, Chicago, IL. (Doug Thistlewolf attended the 2015 Museums and the Web Conference (MW2015) and presented project findings at this professional forum, where he described the affordances and limitations of a whole museum WiFi triangulation based indoor positioning system as compared with camera, BLE beacon and Near Field Communication (NFC) tracking systems. In addition to sharing project findings with the forum attendees, Thistlewolf spoke informally with many conference participants about the details of WiFi triangulation based tracking systems.)

Workshop Participation: Next Generation Informal Assessment Workshop, July, 2015, at the NY Hall of Science. (Joyce Ma was one of 45 learning scientists, data scientists, and museum professionals invited to attend this NSF-funded workshop. There she shared findings from the IPS project regarding the limitations of WiFi based location systems and BLE beacon proximity systems during roundtable discussions.)

Panel Presentation: Pillsbury, C., Chan, S., Patten, D. & Devine, S. (2015, October). *Mobile Technologies in the Museum: Reports from the field and prognostications*. Presentation at ASTC 2015, Montreal, QC, Canada.

Paper Presentation: Ma, J. (2016, July). *Using sequence analysis to understand visitor behavior*. Presented at the 2016 Visitor Studies Conference, Boston, Massachusetts.

**CONTRIBUTION OF THIS RESARCH:**

This research provided significant findings within two main arenas. The first is in the research and development of indoor positioning systems. Even when the particular device or strategy fails, the research findings are extremely useful to the rest of the field. For instance, the ability to calculate the relative amount of "bleed" into other galleries, and inaccurate positioning of the visitor is useful.

Secondly, the Exploratorium has established rigorous protocols for ground-truthing indoor positioning systems, and a suite of protocols and tools for analyzing data from such a system. This is of enormous benefit to the field.

The third, less prominent potential findings are in the arena of visitor research around mobile, location-aware interaction. Will visitors find, and contribute to, content that was specifically designed for a particular interactive and delivered through a mobile device? The Exploratorium has documented that if alignment of content and location is off, visitors will be confused by the additional commentary.

**SUMMARY:** Overall, this work has contributed greatly to the informal learning field in helping better understand the challenges and rewards of indoor positioning. I would like to note that the team in particular has been wiling to try out new technologies rigorously, problem-solve challenges and push the field to be innovative. Even the result where the Exploratorium was unable to provide exhibit level positioning through WiFi or beacons is enormously useful to the field, as many institutions and companies claim to have 'solved' indoor positioning at this level. Indeed, it is a common perception within the field that this technology exists. The Exploratorium team has rigorously tested multiple solutions and documented the current capability and issues with museum galleries.

My strong recommendation is to continue to find venues for the dissemination of these findings and tools, through InformalScience.org, CAISE, conferences, and other opportunities.

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