September 2014

Noise Pollution Exhibit at the EcoTarium

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An Interactive Qualifying Project Report

Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

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Date: September 2, 2014

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Abstract

Our project team designed, developed, and tested an educational interactive display about noise pollution as part of the new City Science exhibit at the EcoTarium Museum of Science and Nature. Collaborating with the museum staff, we created a Java application to run on a touch screen computer. After we tested the application and developed it into a working prototype, we made recommendations for further ways to enhance the exhibit. Our results show that the exhibit successfully demonstrated how people's responses to noise are subjective, and visitors who used the exhibit often engaged each other in dialogue concerning noise pollution.

Acknowledgements

We give our sincere thanks to the staff at the EcoTarium who helped us with this project. Alice Promisel and Betsy Loring provided us with great feedback, and Eric Zago always knew how to help us on the technology end. We would also like to thank our project advisors, Dominic Golding and Anne Ogilvie, for guiding us every step of the way with the project and the report. In particular, we owe a huge thank you to Shana Hawrylchak, the new Manager of Exhibits at the EcoTarium. She came to the EcoTarium in the middle of our project and immediately involved herself in what we were doing, and she provided invaluable experience and expertise to help us develop our prototype.

Executive Summary

The EcoTarium Museum of Science and Nature is developing a new *City Science* exhibit to educate visitors on topics relevant to urban environments. One of the goals for the exhibit is to demonstrate the effects of noise pollution in cities, where noise sources like traffic, sirens, and neighbors are abundant. The museum staff tasked our group with creating a Java application for visitors to use that focuses on the idea that people respond differently to noise. Since the EcoTarium focuses primarily on educating and entertaining families with young children, the application had to be very easy to use and contain minimal text instruction.

Noise pollution is a growing concern in the modern world, especially in densely populated urban areas. Even if we are not aware of it, noise can disturb us in our sleep and cause stress and other health problems. People who live in cities become accustomed to common noises. Most can sleep through noises from things like cars, sirens and trains. People who live in more suburban or rural areas, however, find these types of sounds annoying, because they are not used to hearing city noises on a regular basis. A previous IQP group from WPI created a Java application to run on a touch screen display for part of the *City Science* exhibit (Breault, Chen, Keeley-DeBonis, Margiott, 2013). Their application allowed visitors to create "soundscapes" of their own neighborhoods by dragging sound clips onto a timeline. Everyone's neighborhood has a different mixture of noise sources depending on where they live, so different people drag different sounds onto the timeline. The museum staff wanted our application to run on a touchscreen as well, alongside the *Soundscape* display; it should be a natural progression for visitors from the soundscape and reinforce some of the same concepts. The initial idea from the museum staff was for the application to play different sound clips and have a biological sensor to measure the physiological responses of users as they listened to the different sounds. We designed the application to take input from an Arduino microcontroller, and we obtained a galvanic skin response (GSR) sensor and wired it to the Arduino. At this point, a user could select sound clips to play, and the GSR sensor would display his/her relative stress level on a dial on the screen. Theoretically, the sensor would show that we all respond physically to noises, but some sounds induce smaller or larger stress responses than others.

To develop the application, we followed the museum staff's general procedure for developing exhibits. Following their iterative process, we created 5 iterations of our prototype and tested each one on the museum floor, eventually delivering a final version to the EcoTarium staff. Between each visit we updated the application. The touch screen was set up on the museum floor (Figure 3), and we observed visitors using the application. Our notes from the visits and feedback from museum staff guided our design updates. By using this process, we observed that the GSR sensor was too inconsistent to be of practical use in a museum setting. We replaced the sensor data with subjective responses. After hearing each sound clip, users selected 1 of 5 responses indicating how the sound made them feel. The last major update was implementing “2-player” mode and displaying the application across 2 touch screens. In this mode, the 2 players cannot see each other’s screen. Players take turns selecting sound clips to play and choose their responses secretly. After both users make a choice, they each get to see the other’s response (Figure 12). When the responses are different, users often discuss their respective choices. In both the 1- and 2-player modes, users can compare their responses to graphs that show the total responses of all users over time.

We achieved our main goals. The first goal was to encourage visitor retention and extend exhibit dwell time. According to the EcoTarium staff, a museum exhibit is considered successful if people pay attention for 20 seconds or longer. Most people used our application for a minute or longer before walking away. The second goal was to encourage visitor engagement and provoke dialogue between friends and family members about the topics of noise and noise pollution. People of different age groups and backgrounds had very different responses to some of the sounds they heard, and this generated intra-group discussions on the subject. We recommended to the museum staff that they create a method for measuring how much information visitors learn from using our application, and they also plan on adding informative text panels in the final exhibit to complement the information presented on the touch screen monitors. When they add the accompanying panels and fabricate the final design, our application will become an integral part of the City Science exhibit.

Authorship

For most parts of the paper, one person drafted each section, and someone else revised it. We divided the literature review equally amongst the group. Each member researched 1 of the 4 research topics and drafted one section. Each section of the findings was drafted by whoever made the corresponding trip to the EcoTarium for testing. Derek Calzada, Kyle Lafontant, and Alex Stylos each drafted one section of the methods.

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Abstract	Gabriel Bell	Gabriel Bell
Executive Summary	Gabriel Bell	Gabriel Bell
Introduction	Derek Calzada	Derek Calzada
Museum Exhibits	Kyle Lafontant	Kyle LaFontant
Learning in Museums	Alex Stylos	Alex Stylos
Exhibit Design	Alex Stylos, Kyle Lafontant	Gabriel Bell
Digital Technology in Museums	Derek Calzada	Derek Calzada
Noise Pollution	Gabriel Bell	Gabriel Bell
Methods	Derek Calzada, Alex Stylos, Kyle Lafontant	Alex Stylos, Derek Calzada
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1. Introduction

Our goal was to create an interactive display that teaches visitors about noise pollution and perceptions of noise for the new City Science exhibit at the EcoTarium. What one person considers objectionable noise or noise pollution may not be considered so by another person. This is an especially important topic in a city setting such as Worcester, Massachusetts, where there is much ambient noise. Many people may not think about noise pollution and its effects on our health. Our hope was to make visitors of the EcoTarium more aware of the noises in the city and their neighborhoods and how they may affect them, their children and those around them.

A previous IQP group from WPI created a Java application to run on a touch screen display for part of the *City Science* exhibit. Their application allows visitors to create “soundscapes” of their own neighborhoods by dragging sound clips onto a timeline. We designed our application to run on its own touch screen alongside the *Soundscape* display. We modeled the look and feel of our application after the *Soundscape* program. Since many EcoTarium visitors are family groups with young children, the application has to be very easy to use and contain minimal text instruction. We also tried to create a multi-user and multimodal experience that will be encourage familial and group engagement and stimulate conversations about noise and noise pollution. In our background research, we learned that these are all important aspects for designing a successful modern museum exhibit.

People who live in cities become accustomed to many noises and can even sleep through noises that other from ore rural settings might consider loud and annoying, like sirens. People who live in more suburban or rural areas typically only hear the sounds of nature and their neighbors. We attempted to subject visitors to various common sounds that they may hear on a daily basis. The program prompts users for responses as input, making people think about their reactions to different sounds. During our testing, this often prompted conversations within groups of users about how the sounds made them feel and whether or not they felt that particular sounds could be considered ‘noise’.

We used an iterative prototyping process to develop our application, making 5 visits to the museum for testing and making updates in between each one. We observed visitors using the application, and the museum staff also provided feedback on each version. Their feedback, along with our own observations, guided our design updates. By the final version of the prototype, users were intuitively using the program as designed and also talking to each other about noise and noise pollution. People usually listened to most, if not all of the sound clips presented in the exhibit and often spent a minute or more engaging with the exhibit and each other.

2. Literature Review

2.1 Museum Exhibits

Museums have long been established as institutions of learning and are always aiming to expand their ways of teaching the public history, science, and art. Museums achieve their educational role through the display and interpretation of exhibits along with ancillary educational programming. Approaches to museum exhibits and programs have changed dramatically in the past 50 years in response to changing public demands and the findings from visitor evaluation studies (Hein & Alexander, 1998). Below, we discuss how changes in educational philosophies and our understanding of learning in museums have resulted in a fundamental shift in the way exhibits are designed, with an increasing emphasis on interactive, hands-on activities that engage a diversity of audiences, especially families with children. Children's museums and science museums, like the EcoTarium in Worcester, have been on the leading edge of these developments and are turning to digital technology in their efforts to engage and educate. We planned to use digital technology to create a new exhibit at the EcoTarium that teaches visitors about noise and noise pollution.

The International Council of Museums (ICOM) defines museums as "a nonprofit, permanent institution in the service of society and its development, open to the public, which acquires, conserves, researches, communicates, and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment" ("Museum," 2007). Since the early 20th century, most museums in developed countries have had three primary roles: (1) to maintain collections of artifacts; (2) conduct research; and (3) to educate the general public. Museums of the early 20th century served as a place to display interesting objects and historical artifacts. To continue enticing patrons to visit over time, museums have adapted to new developments in learning styles, visitor demographics, and what is perceived as fun and educational. Traditional didactic displays do not actively engage visitors in the learning process. In the 1970s, museums began to incorporate visitor centric behaviorist and constructivist approaches which immediately showed an increased engagement of a wider audience. This new style of display appealed to the public and allowed for a more fun and hands-on way to learn in museums.

One of the most important developments that came from this shift in educational styles was the option to have many types of exhibits rather than the typical "Look, Don't Touch" exhibits of the earlier times. As Gardner's Multiple Intelligences theory tells us, children think and learn in many different ways. He tells us that there are 7 main ways in which children learn: visual, musical interactions, interpersonal and intrapersonal interactions, linguistic, logical, and kinesthetic aspects

(Gardner, 1991). By understanding this, museums could cater more to diverse types of learners, which encouraged new exhibit designs to complement different styles of learning.

In 1998, the Franklin Institute Science Museum, the Academy of Natural Sciences, the New Jersey Aquarium (now the New Jersey Academy for Aquatic Sciences) and the Philadelphia Zoo began working together as the Philadelphia/Camden Informal Science Education Collaborative (PISEC) to conduct research on family learning in three main phases. They wanted to: (1) better understand how families learn and explore how to measure family learning; (2) determine what characteristics facilitate this style of learning; and (3) find out if exhibits had the characteristics necessary to promote family learning (Borun, 1998). Since then, many different studies have been done on the various elements of family learning, and exhibit design has progressed to incorporate those findings. One such study published in 2010 investigated the effect of promoting "group inquiry" in exhibits. In the experiment, visitors progressed through 4 exhibits, either as part of a test group or a control group. Members of the test groups were taught to play special inquiry games at the second and third exhibits in order to promote the specific skills of "proposing actions" and "interpreting results". Additionally, one group focused on individual inquiry and one on family inquiry. The results showed that visitors who's inquiry skills were promoted interacted much more with the final exhibit than members in the control groups, and promoting family/group inquiry yielded much more positive results than promoting individual inquiry alone (Allen & Gutwill, 2010). Another study from 2011 focused specifically on families who visited museums frequently and "how they valued the presence of the interactive family gallery". Overall, having an interactive space was seen as vital, with families often spending half of a museum visit using the interactive exhibits. The results of the study showed that the families valued the following characteristics in exhibits: opportunities to engage interests of different family members, active experiences, child-friendly/energy-burning environments, opportunities to stimulate creativity and imagination, opportunities to practice social skills, and fun (Adams & Ancelet, 2011). These studies support the original findings of the three-year project conducted by PISEC, which concludes that exhibits designed to be family friendly better promote learning. When family learning is focused on in the design phase, exhibits are much more likely to be successful.

2.2 Exhibit Design

To be able to create successful exhibit designs, museums must understand who their audience is, how their audience learns, and how best to facilitate that learning. Museums use school field trips and community visit days to attract younger students and have been able to target specific age ranges for many of their exhibits. Using Gardner's 7 ways of learning, exhibits can be designed to ensure that no children leave the museum without learning something.

People go to museums for many different reasons and take different things out of their experiences. Some go to museums for personal, individual learning. Some go for sociocultural learning (both personal and group learning), or group learning (Falk, n.d.). Increasingly, museums are focusing on a group learning method called "family learning". This is a notion that family members attending a museum together will learn more about subjects as they interact with one another.

2.2.1 Family Learning

Families visit museums for many reasons. They may want to relax and enjoy an afternoon, or gain cultural or educational enrichment. Whatever the reason for going, they will learn something. Studies show that what happens in the home or in the community is as critical as formal education, if not more so, to a person's success in the world. A majority of researchers across different fields of study agree that the family is the first, and often the most, influential learning institution for a person (Dierking, n.d.).

There are 2 parts to family learning from exhibits: personal methods and cooperative methods (Hilke, 1988). Personal methods encompass actions that promote an individual's learning without outside interaction. Examples of personal methods include "looking, reading, or manipulating the exhibit" (Hilke, 1988). Reading about, observing, and interacting with an object increases exposure to the concept the exhibit is trying to present for the individual, which leads to more learning. Hilke observes that despite another family member being close by, walking between exhibits is done alone more than 50% of the time. This leads to the conclusion that the dominant method for learning information from exhibits is by personal methods, such as manipulating objects, that pertain to the exhibit. "Taken together, these finding suggest that individual family visitors pursued personal agendas to learn … and used strategies which allowed them to acquire information first-hand." (Hilke, 1988).

Cooperative methods are used when families share their experience of the exhibit with one another. Usually this sharing of experiences is spontaneous and unsolicited, such as when a child successfully navigates through the interactive phase of the exhibit, or an adult highlights a particular item in the exhibit that they feel the child or another adult may be interested in. Because families tend to announce their findings, they increase the information available to additional family members. This reinforces and augments the information obtained by family members using personal methods (Hilke, 1988). Both parents and children tend to initiate interactions within the family group at an equal rate. This suggests that all family members have an equal chance "to communicate to members of the group and, in turn, to receive communications from other group members" (Hilke, 1988). This communication and information sharing between family members is the essence of family learning.

2.2.2 Interactive Exhibits

For the past 100 years, museums have been broadening their goals and missions, changing for visitor education to become the central concern, and this focus on learning sets the framework for exhibit designs and determining how to best attract guests. As museums have evolved, interactive exhibits have taken over many museum floors. Interactive exhibits are defined as those in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input (Allen & Gutwill, 2004). This radical change to an interactive experience was driven by several factors: findings from visitor evaluation studies, changes in the general public needs and demands, and changes in our understanding of how people learn. Interactivity in museums promotes engagement and understanding and family learning (Allen & Gutwill, 2004). Interactive exhibit design is the most important aspect to family learning.

The shift from didactic exhibits to more interactive ones has contributed heavily to attracting new people and groups to museums. The old didactic style was very uniform; displays had labels or panels that described what was to be learned in front of pictures, sculptures or models. These static displays did not have any way for people to interact with the exhibit itself. This is very similar to the type of learning that is done in public school systems. Teachers organize lessons and present what is to be learned in a rational sequence to students. Students accustom themselves to a very passive form of learning, in which they sit in a PowerPoint presentation or lecture expecting to absorb information (Hein & Alexander, 1998). When moving away from this traditional style, museums began to promote more informal science education (ISE). New constructivist exhibits promoted active learning, teaching and learning strategies that engage and involve students in the learning process ("Active," n.d). The introduction of interactive exhibits in the museum setting, coupled with Gardner's theory of Multiple Intelligences, allowed for exhibits to develop encompassing techniques to cover all styles of learning. That includes helping people of all ages learn new things every time they go to a museum, indicating that museums have a role in society that both supplements formal "in classroom" learning as well as promoting lifelong learning.

2.2.3 APE Style Exhibits

An interactive exhibit can be designed using various methods. One method for improving exhibit design is APE (Active Prolonged Engagement). "The goal of APE exhibits is to provide visitors with opportunities to engage in their own scientific investigations, to question, wonder, and hypothesis." (Tisdal, 2004). When actively engaging with an exhibit, "visitors can bring more of themselves – their fascinations, desires, questions, goals, and expectations – to the exhibit experience" (Exploratorium, n.d.). It can then be assumed that people are gaining valuable information. The longer the duration of engagement, the more people learn.

APE style exhibits promote prolonged interactions with visitors. Interactive exhibits are preferable to static displays due to the personal involvement with the subject (Allen & Gutwill, 2004). Engaging with the exhibit allows visitors to explore more about a subject than just reading about it, because it is a firsthand experience.

There are different types of engagement a visitor can experience while interacting with an exhibit. This includes physical engagement, intellectual engagement, and social engagement. Physical engagement could be reading labels, pushing buttons, or where they sit or stand in relation to the exhibit (Tisdal, 2004). Intellectual engagement is when visitors connect the information to their own existing knowledge. Social engagement is the way in which visitors influence others' experiences at the exhibit, whether they are family members or strangers. This is the same as the family learning process.

2.2.4 PISEC Guidelines

APE style exhibits follow a set of guidelines made by PISEC to ensure that every exhibit promotes an interactive family learning environment. PISEC outlines seven necessary characteristics for promoting family learning. Each exhibit should be: multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant (Borun, 1998).

The first two characteristics, multi-sided and multi-user, allow families to cluster around and experience the exhibit while still allowing interaction for several people. While clustered around the exhibit, the family is more likely to engage in activities such as relating experiences about the exhibit to each other. Multi-outcome means that an exhibit is sufficiently complex to foster group discussion based on observations or interactions. With the wide range of visitor ages that will be using the exhibit together, the exhibit must also be multi-modal, meaning that it appeals to different learning styles and levels of knowledge. Parents can read text to young children, and children old enough to read can be encouraged by text instructions. Overall, to successfully engage people, the information must be accessible and relevant to their existing knowledge and experiences. These characteristics help ensure that family learning is facilitated, while providing adequate subject material to family members of all ages. PISEC suggests prototyping as a general method for improving and developing exhibits. This allows for testing to see if an exhibit appeals to target families and age groups and provides a clear message (Borun, 1998).

2.2.5 Evaluating Exhibit Design

Once interactive exhibits began gaining popularity, a new evaluation process for the creation of successful exhibits and determining their value was implemented. The first step of the evaluation, "front-end evaluation," takes place to help the exhibit team understand exactly who they are targeting. The next step, formative evaluation, uses prototypes to test ideas for their functionality and ability to communicate content to museum-goers. Following that is remedial evaluation, which occurs after completion. Remedial evaluation helps troubleshoot issues before the final exhibit assessment. The final step is a summative evaluation which determines the overall successes and shortcomings while examining behavioral, cognitive, and affective outcomes to the original goals and objectives (Korn, n.d.). This process helps guide the design of exhibits to achieve the highest educational value.

Recently, museums have been using digital technology to facilitate the ways in which they create both physical and intellectual engagement. Digital technology allows for museums to create exhibits with choices, feedback, and more interaction.

2.3 Digital Technology in Museums

The increasing demand by society for digital technology has driven museums to incorporate digital technology into their exhibits. With an estimated 75.6% of household in the Unites States in 2011 owning some form of a personal computer (File, 2013), the use of digital technology is quickly reaching across people from all demographics. This push toward incorporating technology in museums began with the use of personal radios. These radios, first used in 1952 in the Stedelijk Museum (Falk & Dierking, 2008), allowed visitors to tune into a local closed circuit radio station. On these stations, the museum would play audio recording of information on the exhibits. As a user went from exhibit to exhibit, they could tune into the corresponding station and have their own tour guide. By wearing headphones, visitors could advance at their own pace. This sort of technology has persisted more than 60 years later into the modern digital age. Many museums have created apps, such as The American Museum of Natural History's Explorer app, that act as personal tour guides just as the original radio technology did.

According to Falk and Dierking in their book on digital technologies and museums, "Digital media experience have the potential to effectively situate the visitor's museum experience within the broader context of an individual's life, community, and society; they also have the potential to allow significant customization of experience and to extend visitors experiences beyond the temporal and physical boundaries of the institution" (Falk & Dierking, 2008, p. 28). This way of interacting, different from viewing didactic displays of the past, makes it more likely that museum visitors will be engaged and learn. "Digital technologies also facilitate personalization. Freed from the constraints, both physical and interpretative, of the curator and exhibition designer, the learner can use appropriate technologies to provide a dedicated and personal mentor" (Hawkey, 2004, p. 3). Since each visitor has individual interests and learning styles, being able to tailor experiences may be essential for learning. Digital technology allows visitors to customize their own experiences. This also ties into the PISEC guideline of a multi-modal exhibit.

With digital technology, the museum can interface with visitors in ways they are accustomed to. Digital technology surrounds the average person, and this can be exploited by museums. "It [digital technology] can immensely enrich visitors' enjoyment and learning in ways that would be extremely difficult if not impossible to provide through other media. It can provide richly authentic learning experiences – activities and resources that are much closer to those found in the real world, and which cover topics more closely aligned to students' interests than those that can be delivered via traditional educational techniques" (Falk & Dierking, 2008, p. 36). This engagement is a great way to fulfill the APE aspect of a good museum exhibit since it calls for a user to create their own experience. "Digital technologies facilitate many kinds of collaboration – between museum and learner, between different institutions and among learners themselves" (Hawkey, 2004, p. 3). An important factor of APE is the social aspect of engagement, so it is important that visitors be able to interact with each other and with the exhibits. Digital technology is a platform that can be used to encourage social interaction.

"In an age when personal monologues, dialogues, and multilogues proliferate on the Internet, and museums are adapting accordingly, the social dimension of learning becomes paramount" (Walker, 2008, p. 112). Museums understand the impact that digital technology is having on society and are responding. They also realize that social learning needs to be addressed, as seen with the guidelines for exhibits to be multi-sided and multi-modal.

When creating a modern museum exhibit, technology is important to consider. It can be a flexible tool for museums to use and help an exhibit be engaging. One study on museum goers showed that "visitors greatly prefer interactive elements" in exhibits. Digital technology is a great way to give visitors those interactive elements (Hein & Alexander, 1998, p. 16). According to the Pew Research Center, 56% of Americans own a smartphone and 34% own a tablet. Children are being raised to interact with digital technology, with an estimated 27% of 5 to 6 year olds using a computer on an average day back in 2005 (Vandewater et al., 2007). This interactivity through digital technology has been embraced by society as a whole and is easily extended to the museum setting.

2.3.1 Noise Display

Our project team created a noise pollution interactive display to be a part of the “Neighborhoods” portion of the City Science exhibit at the EcoTarium in Worcester. Visitors learned about the different sounds in their own neighborhoods and about city planning and community improvement. The ultimate goal for our part of the exhibit was to educate adults and children on the topic of noise pollution and its effects on us. Adults learned facts and statistics about noise, and children became more aware of the different noises around them. Because children are still constantly learning how to communicate, they filter out other irrelevant auditory information (Miyara, N.d.). The exhibit highlights sounds and noises that are usually ignored and associate sounds with images that can be manipulated by touch as well as actively measure and display physiological (stress) responses in order to immerse participants in the exhibit.

2.4 Noise Pollution

Noise pollution is the occurrence of unwanted or disturbing sound(s) in our environment (epa.gov, 2012). This includes both noises that only bother us and noises that actually cause us physical harm. It is important to distinguish between the two when talking about noise pollution. Some noises annoy us and may increase our stress but do not directly affect our health. Other noises are loud and prevalent enough to disturb our sleep (directly affecting our health) or damage our ears, causing hearing loss. Advocates of increased noise regulation argue that controlling noise pollution is an important environmental and social issue, but there is a notable lack of research on the effects of noise on humans when contrasted with the existing research on other pollutants (Berglund et al., 1995).

When talking about noise, it is useful to understand the definitions of decibels and Hertz, our units for measuring sound pressure levels and pitch, respectively. The decibel (dB) is a logarithmic unit (base 10) used to measure the ratio between 2 values of electric or acoustic power. When used to measure sound, decibels represent the average air pressure integrated over time in relation to the minimum sound level detectable to the human ear (“Decibel,” 2013). What we hear as sound is our brains’ interpretations of the perceived changes of air pressure in our ears. For reference, a 3 dB increase in sound equivocates to multiplying its volume by a factor of about 2. Normal Speech is around 50 dB, while a rock concert is around 100 dB (Berglund et al., 1995). Hertz is a generic unit of frequency, or cycles per second. In relation to sound, a doubling of the frequency represents a perceived one-octave increase in pitch.

2.4.1 Noise Exposure

Almost everyone is exposed to at least a few sources of noise pollution in their daily lives, whether it is dogs barking or trucks driving by. In cities, exposure is made significantly greater by proximity to pollution sources. The regulations that exist on noise pollution are currently limited by the practicalities of defining and identifying pollution sources and enforcing fines, but many pollutant sources, especially construction-related sources, are regulated. In New York City, for example, citizens can be issued a fine for having an air conditioner that is too loud ("Noise Pollution," 2008), because the majority of residents live in very close proximity to their neighbors in apartment buildings.

Historically, humans have long been responsive to noise pollution. In Medieval Europe, in certain towns and cities, there existed laws prohibiting carriages and horses at night. Similarly, it was illegal in ancient Rome to move a wagon with iron wheels over cobblestone at night (Berglund et al., 1995). Unlike our ability to cut off our sense of sight by closing our eyes, our bodies cannot stop hearing, even while we sleep (Miyara, 2013). While this benefits us by allowing us to wake up in response to sound stimuli, it often negatively affects our quality of sleep. It is easy to cover our eyes, but we cannot prevent our eardrums from receiving vibrations altogether, even with earplugs. That is why practical noise-reduction measures are important. A good barrier next to a highway, for instance, can reduce the noise from traffic by 10-15 dB, making it far lower than the original volume (U.S. Department). Such noise-reducing strategies help preserve quality of sleep for those living near pollution sources.

In the US, there have been two major federal legislations put into effect that deal with the regulation of noise pollution: the Noise Control Act of 1972 and the Quiet Communities Act of 1978. The Noise Control Act of 1972 states that "inadequately controlled noise presents a growing danger" to Americans and federal action is essential to deal with noise from commerce, and it established federal research on noise and noise emission standards (epa.gov, 2012). In 1972, the nation's Interstate Freeway System was 16 years into construction, and the need for increased regulation of noise from commerce was becoming more apparent. Almost ten years later, congress passed the Quiet Communities Act, which transferred some of the authority over noise pollution from the federal to state and local governments. The bill, passed in 1981, "Replaces a finding that Federal action is necessary to control major noise sources in commerce with a finding that Federal action must assure uniform treatment of certain carriers engaged in interstate commerce and certain transportation equipment distributed in interstate commerce which are major noise sources…" (govtrack.us, 2013). While most noise-related issues fall under the responsibility of state and local governments, the EPA remains an authoritative body on the effects of noise in the US and can assist local governments in evaluating noise regulations (epa.gov, 2012).

2.4.2 Physiological Response

The human physiological responses to noise are still being researched, though there is some clear data on the subject. The immediate physiological responses to noise include "increased heart rate, stress, eye conditions, muscle tension, elevated cholesterol levels and hormone secretion, and of course high blood pressure" ("Noise Pollution," 2008). This is the body reacting as though it were in danger. In addition to being affected by the intensity of noise, humans experience emotional responses to certain sounds, such as crying or laughing. These emotional responses influence the activity that takes place in the auditory complex of the brain, further influencing our perception of sounds and affecting our physiological responses (Kumar, 2013).

2.4.3 Health Effects

The ways in which noise affects our bodies over time are not yet fully understood, but there are several defined adverse health effects of excessive noise. The most common negative effect of excessive noise is hearing impairment. Impairment predominantly affects detection of frequencies from 3000 to 6000 Hz, peaking at around 4000 Hz (Berglund et al., 1995). Loud noises damage the small, delicate hair cells in our ears that act as sound receptors, and our range of hearing becomes reduced over time ("Noise-induced"). Hearing loss is not thought to be caused by noise below about 75 dB, and adults should generally avoid exposure to any noise above 140 dB (120 dB for children) (Berglund et al., 1995). For perspective, a piano from 1 meter away played at medium volume is about 80 dB, and a 10 dB increase represents a doubling of average sound pressure (over time) (Miyara, 2013). Men and women are equally at risk for hearing impairment, and just a small deterioration in hearing can weaken speech comprehension (Berglund et al., 1995). Approximately 15% of Americans aged 20-69 have high-frequency hearing loss ("Noise-induced"). Long-term exposure to loud noise (though not necessarily "harmful" levels) may still cause "permanent effects, such as hypertension and ischemic heart disease" (Berglund et al., 1995). Manufacturing and construction equipment is generally loud enough to cause hearing loss. In 2007, 82% of the 23,000 reported cases of occupational hearing impairment were manufacturing jobs ("Noise and Hearing", 2011). Prolonged noise exposure for industrial workers over 5-30 years has also been connected to long-term cardiovascular effects (Berglund et al., 1995). OSHA recommends that workers in noisy environments isolate noisy equipment and pay attention to warning signs of potentially hazardous noise such as ringing in the ears after work or having to shout to coworkers who are nearby ("Safety," n.d.). While most Americans do not work in environments that are hazardous to their hearing, they are exposed to enough noise to potentially impact their health. Daily exposure to non-harmful noise can still elevate stress and blood pressure, disturb our sleep, and have other unknown consequences.

While it may be impractical to wear earplugs everywhere, people can take steps to reduce noise in their own homes, especially at night. Simple things such as avoiding doing laundry at night can make a big difference for sleeping. When sleeping, background noise should not exceed 30 dB (about a whisper) or it can cause "difficulty in falling asleep; awakenings and alterations of sleep stages or depth; increased blood pressure, heart rate and finger pulse amplitude; vasoconstriction; changes in respiration; cardiac arrhythmia; and increased body movements" (Berglund et al., 1995). Noise pollution interferes with speaking and other daily activities by masking the sounds we want to hear. Normal speech is about 50 dB, and the difference between speech and background noise should be at least 15 dB (Berglund et al., 1995). Any noise pollution much louder than talking then causes us to shout to be heard.

2.4.4 Noise Education

An exhibit about urban science would not be complete without noise. In cities, noise is all around us, night and day. The noises visitors hear in the various interactive displays should bring them out of the museum and into a city or nature, highlighting the differences in environments. Our project focused on the responses of our bodies to noise to educate visitors about the effects on our health and quality of life. This is an especially important topic for people living in urban environments, where noise pollution, like any other pollutant, affects everyone on a daily basis.

3. Methods

Our goal was to create an interactive exhibit for the EcoTarium that educates participants (primarily families with young children) on noise pollution and its effects on our health. Our primary objectives to meet this goal were to (1) clarify the nature and purpose of the exhibit, (2) develop an exhibit prototype, and (3) evaluate and refine the prototype. We used an iterative prototyping process, periodically observing how museum visitors engaged with the interactive display, identifying what they learned, and making modifications in response. The prototyping process also evaluated the use of text panels and different graphical representations to help visitors be more engaged. After extensive prototyping and design modifications, we delivered a final prototype to the EcoTarium and made recommendations for further actions they can take to implement the design. This chapter describes our methods used for designing, developing, and finalizing our prototype.

3.1 Objective 1: Clarify the Nature and Purpose of the Exhibit

Our prototype will eventually be part of the new City Science Exhibit at the EcoTarium. The City Science project, titled *From the Lab to the Neighborhood: An Interactive Living Exhibit for Advancing STEM Engagement with Urban Systems in Science Museums*, is being created to teach visitors about the science we encounter in our daily lives but do not usually think about (traffic lights, sewers, etc.). Keeping with that theme, our prototype was designed to educate visitors on noise pollution, particularly showing the effects on our bodies from noise sources encountered in cities, like construction sites and car horns. The original design concept was to use a skin sensor to show participants' physiological responses to different noises. This data, along with the text panels on the sides of the monitor, would be an appropriate amount of information to provide to visitors using the exhibit.

The EcoTarium staff wanted an exhibit that meets the requirements of APE and PISEC, is family friendly, and promotes hands-on, interactive, inquiry based learning. We were also shown a related exhibit, made by the previous WPI group, which allowed users to create a "soundscape" of neighborhood sounds on a touchscreen computer by dragging sound icons onto a timeline. We were told to design the user interface of our exhibit with the same look and feel (and for use on a touchscreen). We researched further into what noise pollution is, what kinds of noises affect us most, and what health effects and physiological responses occur from noise. We determined (1) what biological data the exhibit needed to collect (through sensors), (2) how to measure/interpret that data, (3) what information the exhibit needed to teach, and (4) how to teach that information. Once these determinations were made, we designed the first prototype.

3.2 Objective 2: Develop a Prototype

Since touchscreens have become significantly more prevalent in recent years with rising smartphone and tablet usage, young children often assume any screen to be a touchscreen. This made a touchscreen more appropriate for our design than traditional screen with a mouse. This was not an issue from a programming standpoint as programming for a touchscreen is identical to programming for a mouse. Our interface was similar to the previous prototype exhibit in that it used simple graphics and icons to direct users and to take input. Buttons on the screen were linked to sound files. The buttons themselves were pictures which represented the different sounds (i.e. a phone or a police car). Users kept two fingers on a galvanic skin response (GSR) sensor for measuring stress levels. A dial displayed the information from the sensor on the screen in real time. A version of our interface is shown in Figure 1:

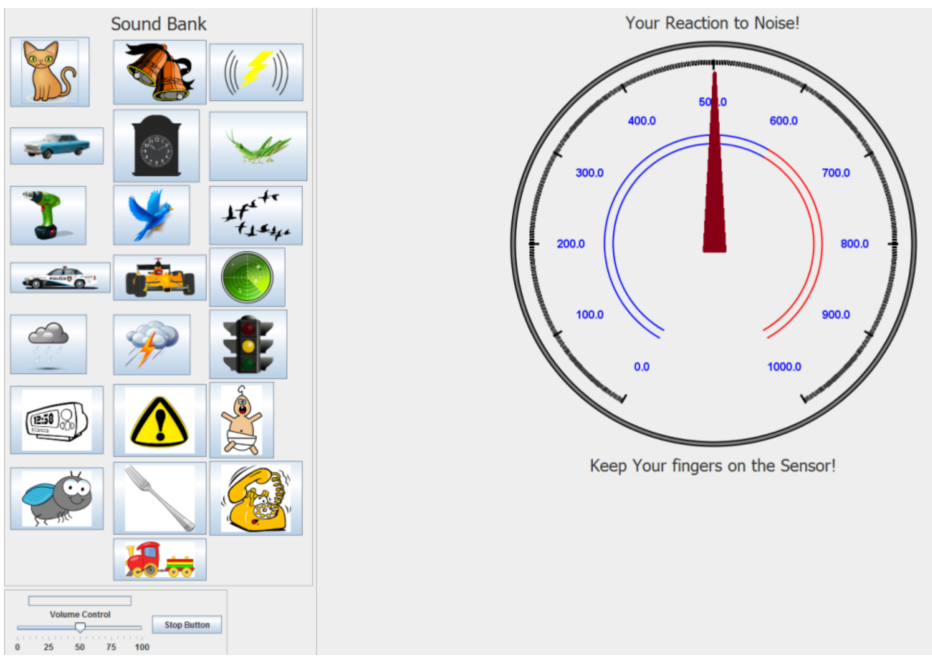

Figure 1: Interface design

It was important to keep the interface simple and intuitive and limit any text-based instructions to a minimum, considering that many museum visitors are too young to read.

Through our research, we determined that using a GSR sensor would be a practical option to measure participants' stress responses. When a person experiences stress, the sympathetic nervous system reacts by increasing sweat gland activity. This leads to an increase in perspiration that can be measured by a GSR sensor, which is really measuring the electrical conductivity of the skin (sweat increases electrical conductivity). We purchased a GSR sensor and wired it to an Arduino microcontroller to translate and send its output to the computer.

Our program framework (Figure 2) consisted of two classes (parts of code), one for the interface and one for handling the sensor data and playing back sounds. Speakers were set up next to the touch screen for the exhibit.

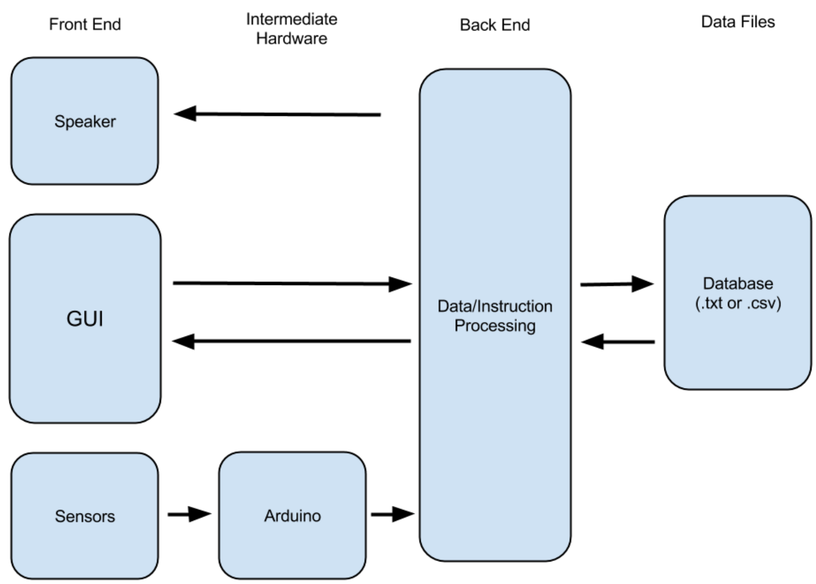

Figure 2: Program flow chart

We chose the sound clips to induce a variety of stress responses, based on what we learned from our research and pictures were found to match the sounds. Once the computer successfully read and displayed the sensor data, our first prototype was complete.

3.3 Objective 3: Test, Evaluate and Refine the Prototype

Testing the prototype on ourselves gave us some preliminary feedback which we used to make alterations before we field-tested a prototype. After we had a tested, functioning prototype, we brought it to the museum staff for evaluation and feedback. At this point, we were able to confirm that we were on track with what the museum expected out of the exhibit before testing on visitors. We were also given feedback on what features the museum hoped would be implemented by the final iteration. We integrated some of these new features into our prototype for the first round of testing on the museum floor.

Floor testing consisted of both actively and passively recruiting museum visitors to test our exhibit. We primarily targeted families with children between the ages of 5 and 9 in order to gather the most useful feedback for our prototyping process. Since the original view for this exhibit was one that was interactive and meant to be used by any member of a family, we were keen in not only measuring children's responses to the exhibit but the responses of whole families. To collect feedback and make other notes and observations, we used special observation sheets (Appendix A). These sheets made note-taking more efficient and helped us translate our observations into iteration results (Appendix B). It was also important to set up the prototype in an area with high visibility and moderate traffic without impeding visitors' interactions with the rest of the museum. By our first prototyping visit, the museum staff had already set up the "Exhibit Development Zone" (Figure 3), which helped legitimize our project to visitors. We decided to limit ourselves to going in pairs for testing, in order to avoid overwhelming the potential participants. During each visit to the museum, we tried to recruit at least two or three families to test the exhibit and give us feedback. This involved either asking families who were already in the prototyping area if they would like to assist us or, if there was no one in the vicinity, going to other parts of the museum to find and recruit testers. Using this method, we were quickly able to get families for testing.

Figure 3: Exhibit Development Zone

During the early phases of prototyping, we explained what our exhibit was trying to achieve and how it worked before participants began interacting with it. As the iterations proceeded, we tried explaining less concerning the use of the exhibit in order to determine how much instruction was needed and how people might act with the final version once it was completed. By gauging responses, we were able to develop ways to make the exhibit more intuitive and self-explanatory. Before allowing visitors to use the prototype, we would first inform them that participating included being exposed to a variety of sounds and attempting to measure their physiological response. Once they consented, we would let them use our prototype. Once a participant/family was satisfied with the amount of time spent the prototype, we would ask them for feedback on our exhibit. This feedback, along with our observation sheets, was our primary source of information when determining which features to implement in the following iterations. It also allowed us to determine the teaching effectiveness of the exhibit. After each update, we went out again for the next round of testing.

4. Findings

After creating an initial prototype, we tested each version with visitors on the museum floor. While visitors used the exhibit, we observed and took notes, paying particular attention to any unexpected results. These unexpected results led to further refinement of the program to increase intuitiveness and potentially increase engagement and learning. For instance, there was no ‘Stop’ button for sound clips in the first version, but almost every user tried to make the sounds stop at some point. We used our observations to make updates and changes after each floor testing session, progressively building into the final version.

4.1 Version 1: Tested on January 26th, 2014

On the first visit to the EcoTarium, the code did not run correctly on the computer with the touch screen. We used an alternate computer without a touch screen to test the user interface. Only one participant tested this version. The user was too young to fully comprehend the exhibit and pressed different buttons in quick succession instead of waiting for sounds to play. He did however seem to respond more to the siren and other artificial sounds than to the natural sounds.

At this stage, the exhibit was not very intuitive. We had not yet replaced the text labels with images, so children who could not read did not understand the buttons. The display was very plain overall (Figure 4).

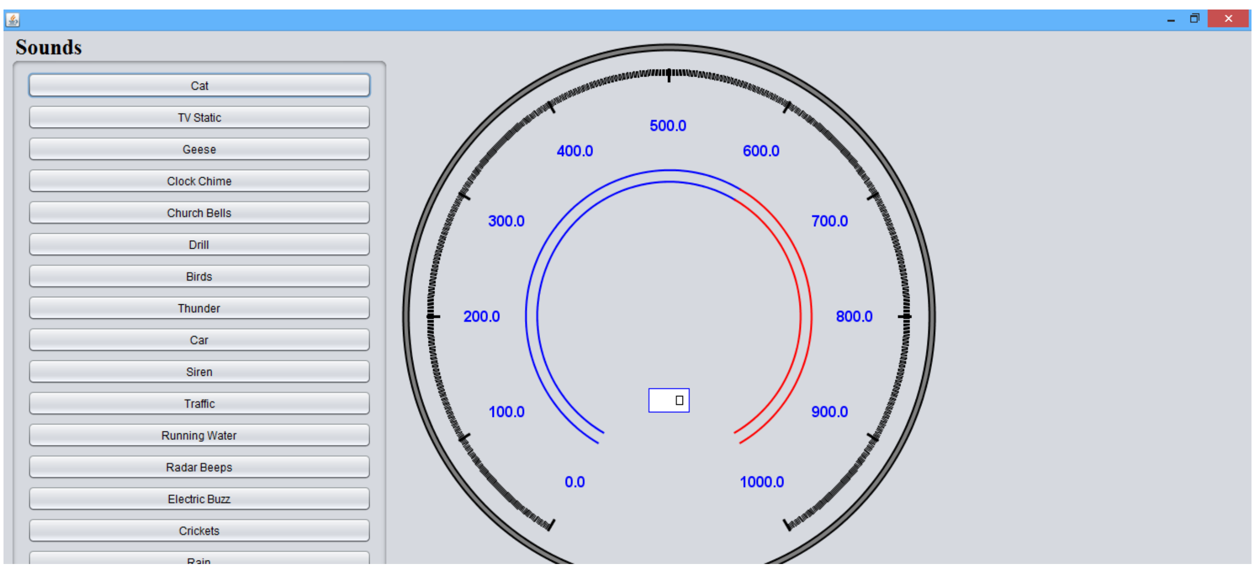

Figure 4: Screenshot of Version 1 Interface

4.2 Version 2: Tested on January 31st, 2014

In version 2 of the prototype (Figure 5), we changed little other than adding in directions as to what the participant needed to do in order to use the exhibit properly. The buttons in this version still had text labels. Participants were verbally instructed to “keep their hand on the sensor” and to select noises on the screen. They were also told that the dial shows them their reactions to the noises.

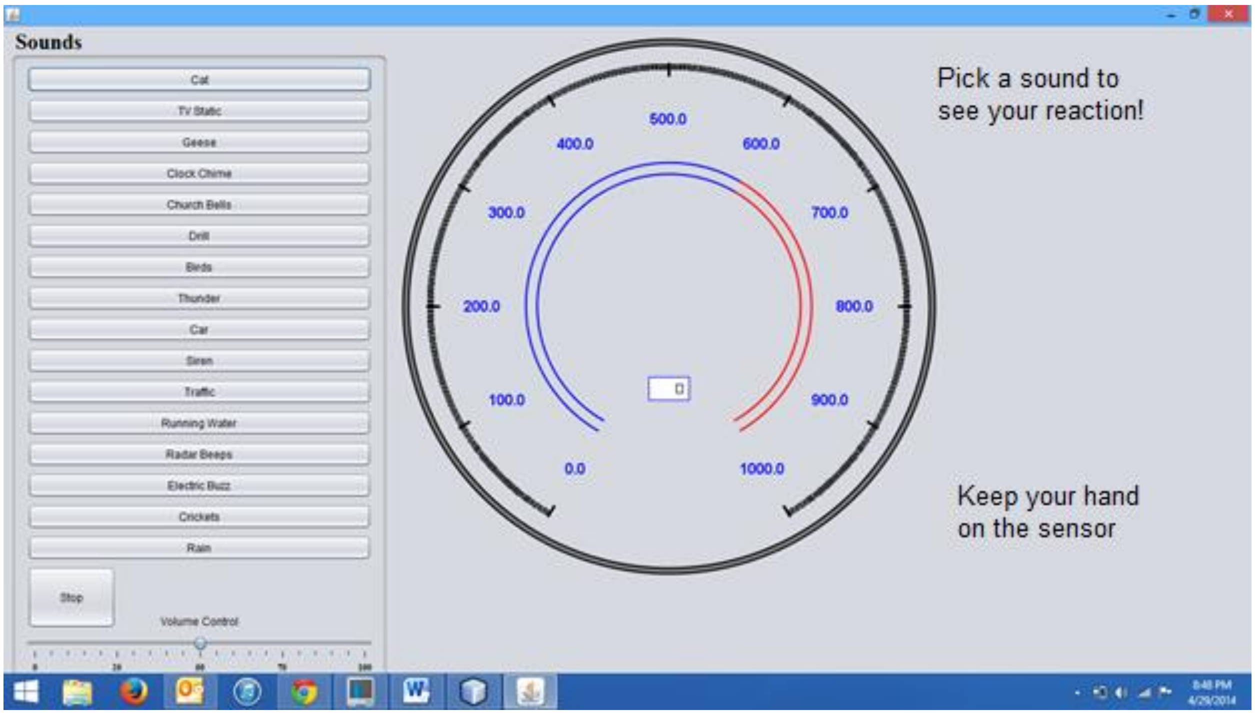

Figure 5: Screenshot of Version 2 Interface

The first group to test version 2 of the prototype was 4 children (ages 4 to 12) and 1 mother. The exhibit was much more intuitive than we anticipated. The oldest child helped his siblings by holding their hands on the sensor, picking sounds for them and telling them what to do. Generally, the younger children did not wait for sounds to finish playing and tapped buttons very quickly. They were also very interested in the speakers and often looked at or touched them. The mother asked us specifically what the sensor was measuring, since we provided no information about it.

The second group was 1 girl (age 4) and 1 mother. Unlike previous participants, the girl did not place her fingers flat on the sensor. Instead she placed only her fingertips on the contacts. This meant the sensor still took a reading, but the signal was much weaker and not as useful. She did notice when she accidentally moved her fingers off the sensor and the dial on screen dropped to 0, and she quickly moved her hand back into place. She also lost interest after about 10 seconds, in contrast to the family who stayed for about a minute.

The third group was 1 boy (age 6) and 1 mother. The mother reminded her son to keep his hand on the sensor while she began to choose noises for him. After a few seconds, the son said, “I wanna do it!” He began choosing many noises very quickly, like the other children, and did not allow any sound clips to play out. He quickly got bored and left.

We found that children generally would not wait for sounds to finish playing if given the option. The exhibit was very intuitive and encouraged families to participate together. Children lost interest quickly, however, and neither parents nor children appeared to be taking away much from the interactive, in part because there were no information panels yet. The noises also did not solicit visible reactions, making the dial boring to watch. In fact, there was only a small variance in needle position on the dial for most sounds. We looked at reasons behind this and identified a few flaws with the sensor.

One problem was that the more skin was placed on the sensor the larger the dial reading. This was a problem, because children’s hand sizes are smaller, and thus cover less surface area on the sensors. We also couldn’t easily explain to people how the reading of the dial related to the noises being played. Differences in humidity, the manner in which the sensor was held, and perspiration all influenced the sensor readings. This meant that from person to person, the baseline reading could be very different and different reactions could result in similar changes in readings.

4.3 Version 3: Tested on February 14th, 2014

In version 3 of the prototype (Figure 6), we replaced the text with images. We chose images that best illustrated the particular sound. Initially, we noticed that participants, especially young children, would press buttons randomly without listening to the sounds, presumably just for the sake of pressing buttons. To counter this, we purposefully made it so that all sound selection buttons would be disabled, by graying them out while the sound played. Pressing the buttons which were “grayed out” would not cause sounds to be played. This meant that the buttons were effectively disabled while a sound was playing. We also added labels on the screen for the sound bank and the reactionary dial. We added the written instruction “Keep your fingers on the sensor” in this version of the prototype. We gave participants verbal instructions as needed.

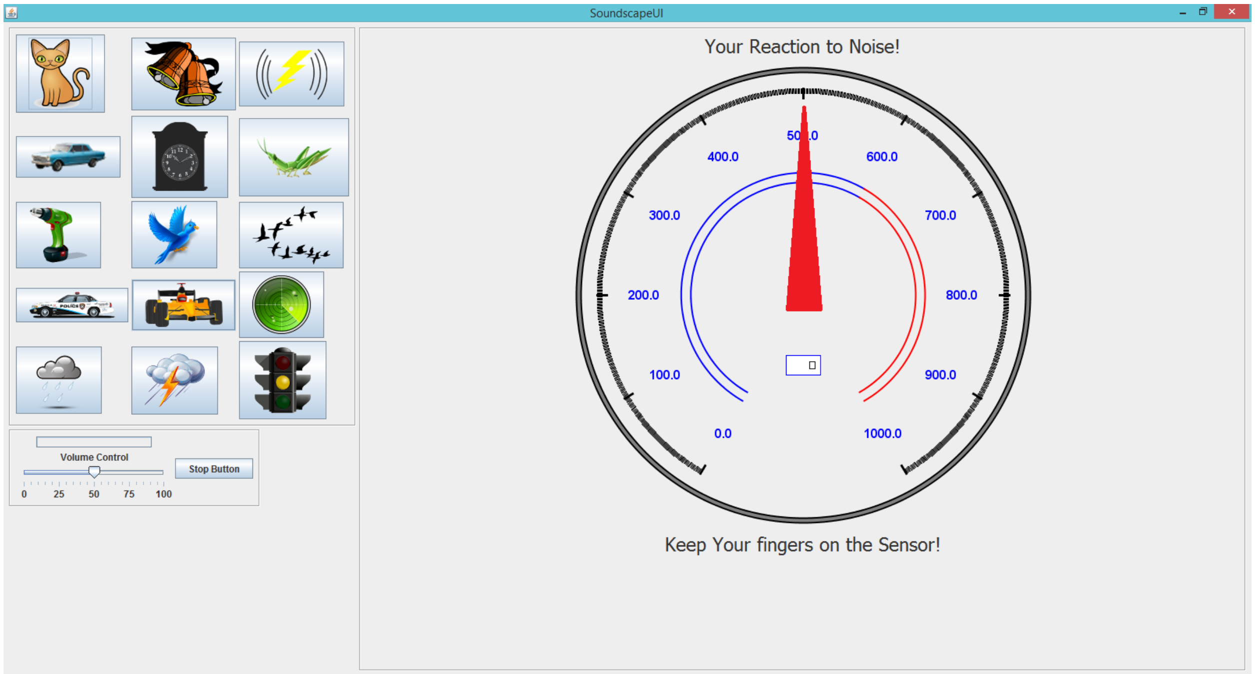

Figure 6: Screenshot of Version 3 interface

The first person to test version 3 of the prototype was an elderly female museum volunteer. She patiently went through all the sounds, speaking her thoughts as she went. She described the exhibit as “interesting”. She said that the siren and thunder noises were most annoying of all the sounds. Unfortunately, we observed no significant reaction on the dial for any sounds, but the signal steadily climbed higher the longer she kept her hand on the sensor. We inferred that this was due to increasing hand temperature and sweating, which is exactly what the sensor is supposed to measure. This is again a problem we had seen before, where external factors such as temperature and amount of skin contact cause a change in the measurement of the sensor. This is unwanted data, because it skews with the actual change in skin conductivity when listening to a sound.

The second group was a boy (age 3) with his parents. His fingers were actually small enough to fit 2 fingers on the sensor where only 1 should fit. He had difficulty keeping his hand in place and constantly shifted his fingers to be more comfortable. He seemed to enjoy the interactive and went through all 15 sounds out of order but still remembered when he had listened to each sound once. He stopped after listening to all the sounds, which seemed to him like a natural point to leave the interactive.

The third participant was another museum volunteer who was in her 20’s. She consciously tried to select “different kinds” of sounds in sequence (i.e. sirens then birds) to see changes in her reactions though this did not yield any significant changes in readings. Similarly to the previous user, she went through all the sounds once before stopping. She was also curious what the sensor actually measured. She expected the “man-made” sounds to be louder than the “nature” sounds.

The last group was a male in his 20’s and his girlfriend. Like the previous participants, he went through all the sounds once. He was also curious about what the sensor was really reading. His reactions did not tell us anything we did not already know concerning the use of the sensor. He also did not note how different sounds made him feel, nor could we discern any visible changes in his demeanor or sensor readings when he experienced the sounds.

Listening to each sound once seemed like an intuitive length of time to spend using the exhibit. The sensor so far had not provided adequate feedback to help enhance the learning experience. No significantly startling or annoying sound clips included in the exhibit yet. Our next goal became adding noises that would solicit stronger and more differentiated reactions as demonstrated on the dial.

4.4 Version 4: Tested on February 18th, 2014

Version 4 of the prototype (Figure 7) contained 7 new sound clips that we chose to be particularly irritating noises: an alarm ringing, a baby crying, a fly buzzing, a fork scratching on a plate, a phone ringing, a train passing close by, and one sound we created particularly to annoy humans that sounds like a high pitched, pulsing noise.

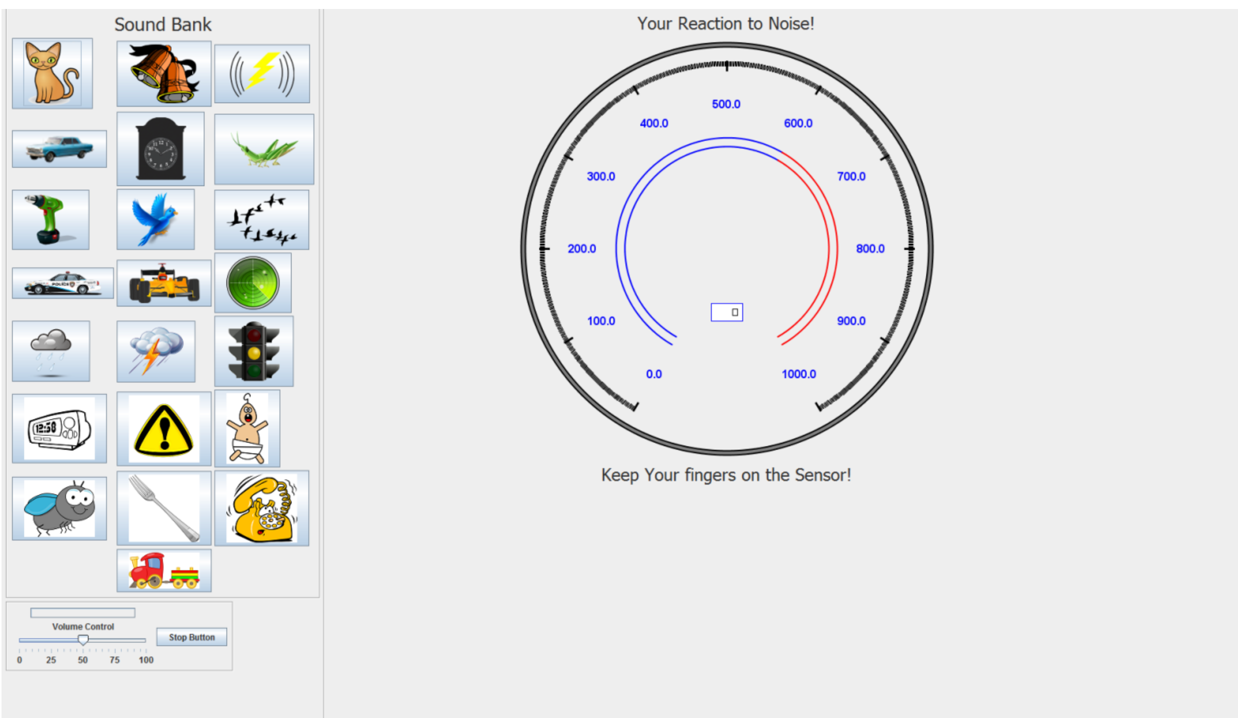

Figure 7: Screenshot of the Version 4 interface

The first group to test version 4 of the prototype consisted of a boy (age 7) and his younger brother. The brother watched attentively while the boy went through the different sounds. Though he did well keeping his hand on the sensor, he seemed to not pay any attention to the dial and instead looked at the buttons as he went through the different sounds. He also stopped most of the longer clips after about 10 seconds (longer clips consisted of 20-30 seconds of sound). He did comment that the sounds were annoying and was clearly affected by the new sound clips, but the dial still did not perform to our expectations. It was at this point we started discussing the usefulness of the sensor, and whether or not it could be replaced, with either another type of sensor or something else entirely.

The second group included a young boy and a girl (both age 6) who both attempted using the exhibit. The girl intuitively assumed the dial was showing the volume of the sounds played, ignoring the label above the dial. We had not anticipated this issue. The participants said the most annoying sounds were the fly and the fork on a plate. The girl liked the sound of the baby crying. The parents did not. When asked what sounds she would like to have heard, the girl suggested adding in a dog barking.

At this point in the prototyping process, we concluded that the GSR sensor would not work well enough to gauge a user’s response to a given sound. The baseline readings of the sensor were not consistent from one user to another and were also affected by humidity and how a user held the sensor. This often led users to be confused since the readings from the sensor could not be directly linked to their reactions.

During this time, the museum had begun to experiment with other approaches to the exhibit. Museum staff requested that two visitors sit across from each other with a board in between them (Figure 8). On the board were images of various sounds that visitors could point at to choose. Included were two mystery sounds which had no images or descriptions.

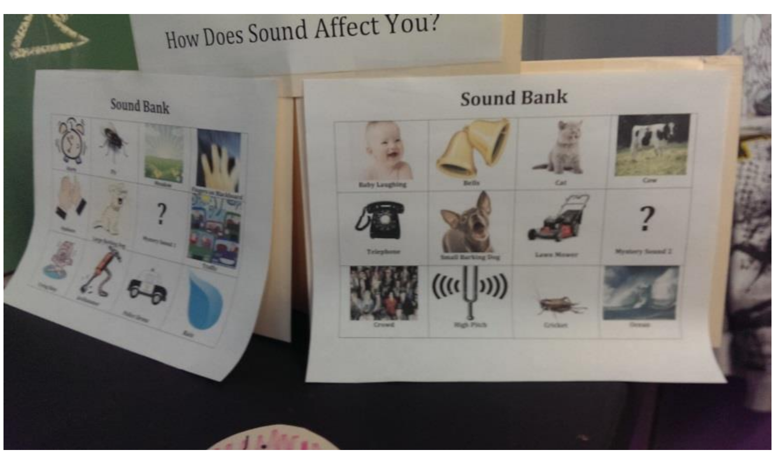

Figure 8: The museum staff’s paper prototype of our exhibit

Participants sat on either side of the board facing each other. They alternated choosing sounds from the board. Once a sound was chosen, a member of the museum staff who was closely observing the participant’s choices would play that sound for both users to hear. Participants would then hold up one of five responses (Figure 9) representing how the sound made them feel. These consisted of five paper faces ranging from happy to angry.

Figure 9: The Likert-type scale used in the paper prototype

This new approach to the exhibit eliminated the need for a sensor and allowed users to gauge their own reactions. The museum staff found that this version led to discussion among testers and even bystanders as to how people responded to different sounds. This meant that there was more engagement with the exhibit as well as interaction between visitors, two important keys in learning in a museum environment. Because of the difficulty posed by interpreting the sensor readings and the success of the museum’s new prototype, we incorporated their ideas into the next version of our program.

4.5 Version 5: Tested on February 20th, 2014

Version 5 of the prototype (Figure 10) included five additional buttons for users to choose to indicate their reactions to particular sounds, (1 = angry, 5 = happy). We removed the original stress dial from the screen entirely, and we enlarged the stop button to be easier to select. No sounds were changed between the previous version and this one.

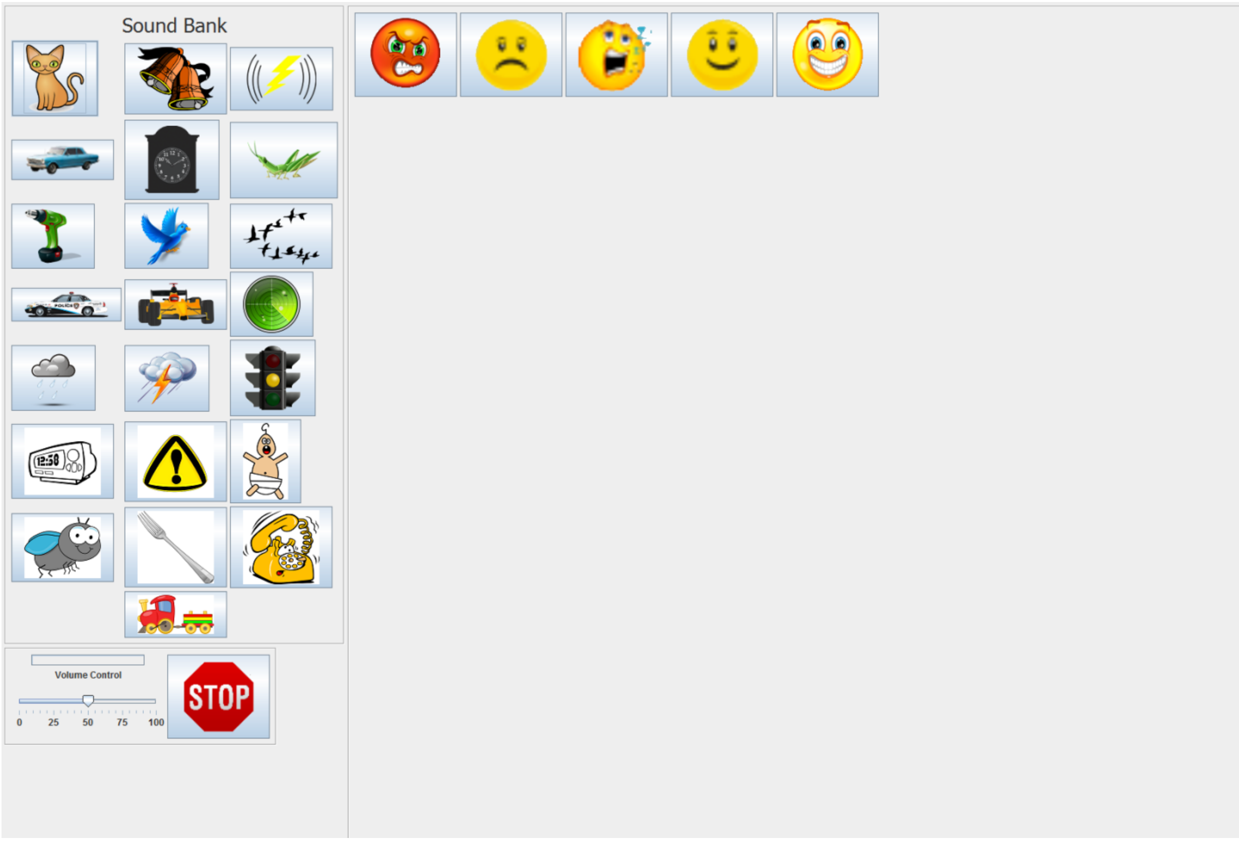

Figure 10: Screenshot of interface using Likert Scale

The first group to test version 5 of the prototype included a mother and daughter (age 3). The daughter stepped up to the display and started playing sounds before we attempted to explain the exhibit. We explained the purpose of the 5 reaction buttons to the mother, and she relayed the information to her daughter. After playing three different sounds, the daughter left the prototype. She repeated the baby crying with two different reactions, rating it as ‘1’ first and then ‘2’. She rated both the telephone and the fly sounds as ‘5’.

The second test group included a family of two daughters (ages 4 and 6) and a mother. Again, we explained the reaction buttons to the mother, and she explained to her children. It was not clear that the children correctly understood the instructions for the rating system. The daughters took turns pressing sounds and reactions. It seemed that they expected each sound to end as soon as a reaction button was pressed. They quickly understood the meaning of the stop button when they realized the reaction buttons did not stop the sounds. Each daughter chose 3 sounds. Both girls rated the train and plane sounds as ‘4’. One rated the alarm as ‘1’ and the cat as ‘5’, and the other rated the drill and birds both as ‘5’.

The third participant was a young boy (age 3). He played one sound and walked away before we had the chance present the exhibit to him.

The fourth test group included a daughter (age 4) and her father. Like with the previous participants, we explained the reaction buttons and the father relayed the information to the daughter. Again, it was unclear if the daughter correctly understood the instructions. The daughter picked two sounds. She rated the fly as ‘3’ and the train as ‘5’.

The fifth group was a son (age 5) with his father. After hearing our instructions, the boy seemed to correctly understand what to do. He also expected the sounds to stop immediately from a reaction being chosen. When the first sound did not stop, he found and pressed the stop button. He rated the fork on a plate as ‘3’, the alarm as ‘4’, and the tolling clock as ‘2’.

The last group was a family of a mother, two sons (ages 4 and 6), and 2 daughters (ages 2 and 6). The oldest daughter really drove the group to try the prototype. We explained the reaction buttons to her, and she relayed the information to the other children as intended. The younger brother went first. Like the other children, he seemed confused when the sounds did not stop, but he quickly found the stop button. When both brothers were done, the older sister placed the younger sister in front of the prototype and prompted her to choose sounds. They went through most of the sounds before the mother told them it was time to go. The baby crying, fork on a plate, alarm, and traffic sounds were all got a ‘1’ rating, the siren ‘2’, the clock and train ‘3’, the phone ringing ‘4’, and the cat and fly bot ‘5’. The thunder sound got a ‘1’ from one child and ‘5’ from another.

This prototype was a large improvement over the versions with the sensor and dial. We finally had data that relied solely on people reacting to the sounds rather than false information from the sensor. This also had the bonus of showing that a person's reaction to sound was subjective, and varies from person to person. To this end, we thought we could further show this connection by graphing how everyone who has ever used the prototype reacted to the specific sounds. Our next step was to write code to make the application record participants’ reactions and display, in some fashion, the data collected over time. Additionally, to closer resemble the paper version tested by the museum staff, a second touch screen was added to the exhibit, and we were tasked with creating “2-player” functionality. Ideally, 2 visitors should be able to choose their own reactions to sounds simultaneously and then compare their reactions to each other and to the previously recorded data, hopefully provoking discussion about their different responses. This discussion of which sounds some may consider pleasant versus others considering annoying or vice versa is the real goal of the exhibit in terms of getting visitors engaged.

4.6 Final Prototype

In the final version of the prototype (Figures 11 and 12) we added a bar graph in order to compare a user's reactions to those of previous users. We also added the option to use the exhibit in two-player mode with the addition of a second touch screen.

We delivered the source code (written in Java) for the final prototype to the EcoTarium staff when we all agreed the program was at an appropriate stage of development. The core of the program will stay the same, and the images and instructions will be updated and replaced by their staff for the fabrication of the exhibit. Pictured here are screenshots of 1 player mode (Figure 11) and 2 player mode (Figure 12).

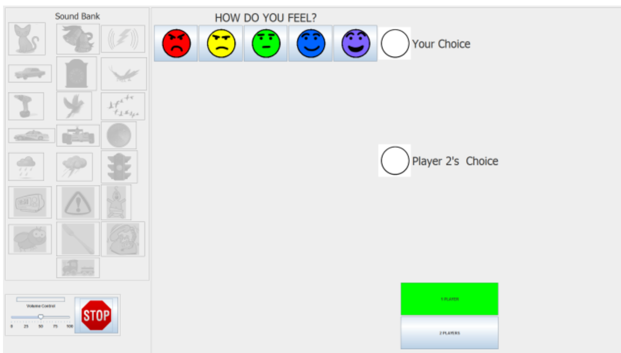

Figure 11: The final version of the prototype, shown in 1 player mode

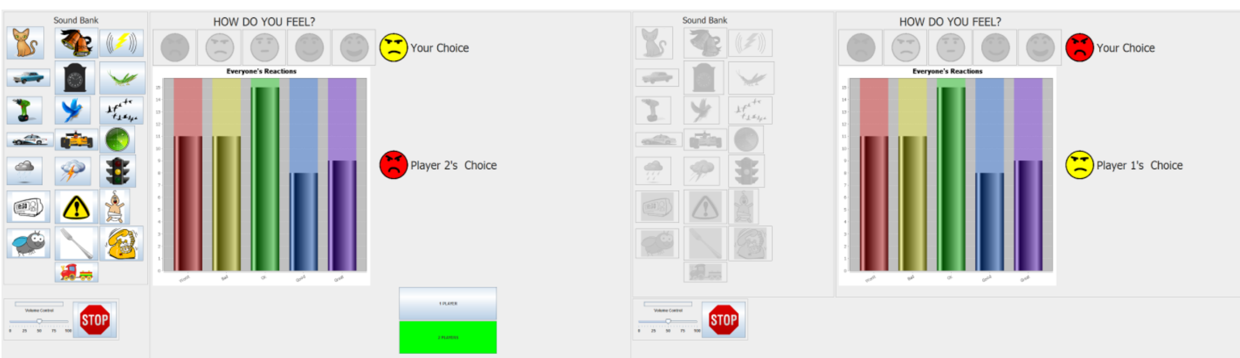

Figure 12: The final version of the prototype, shown in 2 player mode.

Though the final version was not tested on any visitors of the museum, it was used briefly by the EcoTarium staff in order to provide feedback on the final changes. The museum staff was impressed with the usability and features of the user interface. The addition of the graph was a success in adding to the interactivity of the exhibit. Being able to use 2 player mode also allowed the exhibit to become more like a game, adding more interactivity and greater appeal to the exhibit.

5. Conclusions

Based on our findings we draw several conclusions regarding prototyping, exhibit design, and learning outcomes.

Prototyping

The iterative prototyping process is essential to exhibit design. When testing each version, we encountered unpredictable results that guided our design updates. Visitors most often do not understand all aspects of an exhibit that designers thought would be intuitive, so it follows that visitors must be observed using an exhibit to properly assess its effectiveness and its limitations. Only a small number of museum visitors were needed to test each version of our prototype. Observing a few users revealed substantial amounts of information and quickly showed us the weak spots in our design. With larger groups, visitors tended to repeat the same behaviors and mistakes thus confirming, but not changing our observations.

Similarly, it would be difficult to evaluate the effectiveness of an update with many changes. We progressed through design revisions very quickly. By making small changes for each revision, each change was more explicitly tested. This also ensured that we retained whatever functionalities and levels of interaction we had already achieved, and we effectively and efficiently produced our final exhibit.

Going to the museum in pairs worked very well and simplified testing. It allowed for one person to recruit, assist visitors, and prompt them with questions while the other took notes and observed. Having an area set up for testing made recruitment very easy. The testing area looked nice, with a large colorful sign, and was conveniently located outside the cafeteria. To complete the visual appeal, the colorful features on the digital interface itself gave the exhibit immediate 'attractive power' for visitors. This is one key element of successful APE exhibits.

The paper version of the prototype created by the EcoTarium staff showed us that very simple displays can be enough to begin testing an idea. While they proceeded on their own, we had been trying to redesign the digital interface less successfully. This is a great example of why it is beneficial, and necessary, to test early on in the design phase, even with rudimentary mock-ups. Trying to perfect a museum exhibit before observing people use it is a waste of time. It was important for us during this stage to actively discuss our observations and goals with evaluators, museum educators, and advisors. Throughout the iterative process, perspectives on design criteria, design options, and learning outcomes evolve dynamically.

Exhibit Design

Our final design only vaguely resembles our first prototype. The GSR sensor was initially a key component, and we incorporated it in Versions 1 through 4 of the exhibit. Both we and the museum staff thought that this sensor would provide a concrete, objective way to measure a person's response to noise. In the early versions, the sensor was largely useless to users, and we tried different approaches to present the skin sensitivity data in more meaningful ways and to make the dial more relevant to the rest of the display. As we proceeded further into testing, it became apparent that the sensor was too inaccurate to be useful, and was inordinately susceptible to changes in humidity, temperature and finger placement. At that point, the museum staff created the paper version of the exhibit that asked participants to choose their own subjective responses to the noises, on a scale of 1-5. This idea of using only subjective responses to the noises to engage visitors allowed us to dispense with the sensor altogether, and we redesigned the exhibit to take subjective responses as input.

We have not conducted a formal summative evaluation, but we conclude that the exhibit design may ultimately prove quite successful according to the PISEC and other design criteria for the design of family-friendly exhibits:

- The intuitive user interface allows relatively young children (4+) to understand quickly how to operate the exhibit with limited written or pictorial directions.
- The multi-user design encourages peer-to-peer, sibling, and parent-child interactions.
- The design is accessible and can be comfortably used by children and adults,although some design elements may need to be modified for final fabrication to make it universally accessible.
- The science concepts are relevant and related to visitor knowledge and experiences as evident from the visitor discussions we observed.

While we did not evaluate the prototype explicitly using the APE criteria, the prototype appeared to be immediately attractive (as shown by ease of recruitment). The exhibit will likely need additional work and text panels to encourage longer engagement and more extensive interchange to promote desired learning outcomes. Finally, while we did not formally evaluate using the ACII criteria, we did notice that parents or other adults took on a variety of roles while interacting with children at the exhibit, including supervisor, player, co-learner, interpreter, and facilitator.

Learning Outcomes

The use of a touch screen exhibit proved to be effective in providing an intuitive way for users to interact with the exhibit. Even young children would quickly begin to press buttons on the screen as they expected a response. The main difficulty experienced by users was the use and interpretation of the skin sensor and dial. When it was removed, the use of the exhibit was streamlined.

While the prototype appeared to meet many of the PISEC and other design criteria it remains unclear what are the fundamental learning outcomes of the exhibit. From our experience, it appears that it is extremely difficult to clearly articulate in advance what are the desirable learning outcomes of an exhibit. The learning outcomes may change during the course of exhibit testing and development. If the exhibit encourages active prolonged engagement and is well designed to promote open-ended family learning, does it matter that the fundamental learning outcomes remain unspecified? Our own exhibit shifted focus to subjective ratings of different sounds from initially highlighting physiological responses to noise.

Our predominant goal setting out was to educate visitors on the subject of noise pollution. Our final prototype engaged users effectively, and it typically stimulated conversations between visitors discussing their different responses. We had no tool or method for measuring how much people actually learned from the exhibit, though it did appear to be attractive to the average visitor and many conversations were brought about from its use. Once visitors used the exhibit, they would often discuss their reactions to the various noises with each other. This helped us evaluate the effectiveness of the exhibit by showing us that it led the users to think about their perceptions of noise and of noise pollution.

6. Recommendations

Museums should always use iterative prototyping to test exhibit concepts and designs since what may seem intuitive and understandable to museum staff may not be so intuitive or understandable to visitors. Designs should be tested early before ideas are set in stone, and simpler mock-ups are initially preferable to more elaborate or polished prototype models. Input should be sought from a variety of people, including those at other museums in order to refine both approaches to prototype testing and exhibit concepts and designs, as well as to promote professional development and in-house capacity.

Before it is integrated into the City Science gallery, the EcoTarium should do several things to ready our prototype for final fabrication. Ancillary materials to supplement the computer interface should be developed and tested, including the use of text and graphic panels for audiences with different interests and levels of knowledge; the material should also include concise information on subjective noise responses that is reinforced by the exhibit. We have communicated with the EcoTarium's exhibit technician (Eric Zago) and gone over how the source code for the program works. We provided the instructions on how to change out the sounds and images as desired, as well as how to change the functionality of different buttons in the program. Finally, summative exhibit evaluations should be conducted to determine the effectiveness of the exhibit in meeting the EcoTarium's goals for the exhibit.

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Appendix A: Observation Sheet

Noise Pollution
Observation Sheet

Version # _______

Observation # _______

Date: ______________

Observer: ____________________

Time Engaged: _______ seconds

Gender: M F

Age: <4 5-11 12-18 18-25 26-65 66+

Group Type: FAMILY SCHOOL GROUP

OTHER ___________________

Visitor Actions

- ☐ Able to use interactive without verbal instructions
- ☐ Tried more than 5 sounds
- ☐ Parent selected sounds for child

Other:

Visitor Conversation

Usability Comments

Survey: Which sounds affected you the most?

Appendix B: Iteration Results

Noise Pollution
Prototyping Results
Friday 1-31-2014

Version 1: This version of the prototype had buttons for playing sounds and the stress dial (and a volume slider) on the screen. The buttons only had words on them describing the sounds. Participants were verbally instructed to "keep their hand on the sensor" and select noises to listen to. They were also told that the dial shows them their reaction to the noises.

Findings: n = 3

The first group was 4 children (ages 4 to 12) and 1 mother. The interactive was much more intuitive than we anticipated. The oldest child helped his siblings by holding their hands on the sensor, picking sounds for them and telling them what to do. Generally, the younger children do not wait for a sound to finish playing and tap buttons very quickly. Children are also interested with the speakers and often looked at or touched the speakers while using the interactive. The mother asked specifically what the sensor was measuring, since there was no information given about it.

The second group was 1 girl (age 4) and 1 mother. Unlike previous participants, the girl did not place her fingers flat on the sensor, instead placing only her fingertips on the contacts. This means the sensor still takes a reading, but the signal is much weaker and not as useful. She did notice when she accidentally moved her fingers off the sensor due to the needle onscreen dropping to 0, and she quickly moved her hand back into place. She also lost interest after about 10 seconds, in contrast to the family who stayed for about a minute.

The third group was 1 boy (age 6) and 1 mother. The mother reminded her son to keep his hand on the sensor while she began to choose noises for him. After a few seconds, the son said, "I wanna do it!" He began choosing many noises very quickly, like the other children, and did not allow any sound clips to play out. He quickly got bored and left.

Take-aways/ Changes: Children will generally not wait for sounds to finish playing if given the option. The interactive is very intuitive and naturally encourages families to participate together. Children lose interest quickly, and, so far, neither parents nor children are taking away much from the interactive, partly because there are no information panels yet. The reactions to the noises currently in the prototype also do not solicit visible reactions, making the dial somewhat boring to watch.

Before Next Prototyping Session:

- Disable buttons after a sound is selected and until it finishes playing or the STOP button is pressed
- Add labels for information on screen and add instructions in written/visual/audio form
- Change buttons from words to icons
- Add noises that will solicit stronger reactions (possibly phone ringing, alarms, cars zooming by, etc.)