Worcester Community Project Center

Robotic Arm Exhibit

EcoTarium Team

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Abstract

Museums like the Children's Museums and Theatre of Maine (CMTM) and the EcoTarium continually strive to produce engaging exhibits that promote family learning since families with young children are their primary audiences. Using design criteria developed by museum researchers over recent decades, we built a prototype pneumatic arm exhibit for CMTM to inspire children's interests in engineering and science. We conducted several rounds of prototyping at the EcoTarium to refine the design. We conclude that the final design was very successful in meeting CMTM's learning outcomes, including the promotion of family learning and active prolonged engagement, and recommend that the museum move to final fabrication of the exhibit.

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Several individuals assisted and helped this project to reach its full potential, and we would like to acknowledge their contributions. First we would like to thank our project advisors Professor Corey Dehner, PhD, JD and Professor Dominic Golding, PhD. They were always there for guidance and kept us on track from beginning to end. Second, we would like to thank our sponsor, Chris Sullivan, from the Children's Museum and Theatre of Maine. He gave us this project, and this is where the prototype will reside. Third, we would like to than Betsy Loring, from the EcoTarium in Worcester Massachusetts, for letting us do most of our testing there. Fourth, we would like to acknowledge AIR Incorporated in Franklin, Massachusetts. They are New England's leading distributor of pneumatic automation components, controls and accessories. Without their help we would not have such an understanding of the pneumatics that we were used or the right valves for the project. Finally, we would like to thank all of the families and groups that visited the prototype in the museums; they are the ones that allowed us to see the impact of this project firsthand.

Executive Summary

Children's museums and science centers continually strive to develop exhibits that appeal to a wide variety of audiences, but especially families with young children since these are their primary audiences. Styles of exhibit design have changed over time from static, didactic approaches of the past to hands-on, interactive exhibits that encourage family interaction and learning. Exhibit evaluation has played a key role in in this evolution. Many museums now engage in extensive evaluation of exhibit prototypes to ensure that the final exhibits are engaging and effective in promoting the desired learning outcomes, such as family learning. The project described herein is part of a larger effort to develop in-house capabilities in evaluation and exhibit design at a consortium of New England museums that includes the EcoTarium (Worcester, MA), the Children's Museum and Theatre of Maine (Portland, ME), the Discovery Museum (Acton, MA), and ECHO (Burlington, VT). We worked closely with staff at the Children's Museum and Theatre of Maine (CMTM) and EcoTarium.

Methods

Our primary goal was to create a prototype robotic arm exhibit that meets the Children's Museum and Theatre of Maine's (CMTM) learning objectives and promotes children's interest in engineering. To achieve our goal, we developed five project objectives: (1) to clarify CMTM's desired learning outcomes for the robot arm exhibit, (2) to develop the design criteria that will ensure the prototype exhibit promotes the desired learning outcomes and meets the other design objectives, such as safety and accessibility, (3) to create a series of prototypes based on the design criteria, (4) to test, evaluate, and refine the prototypes, and (5) to develop recommendations for development and evaluation of future similar exhibits.

We began with a basic 'robotic' arm that had been developed at CMTM through several prior stages of prototyping. We conducted several rounds of prototyping evaluation at the EcoTarium and CMTM to refine the design to promote active prolonged engagement (APE) and encourage family learning. We used establish design criteria, such as those developed by the Philadelphia Informal Science Education Collaborative (PISEC), to guide the design and evaluation process (Borun, 1998). We also consulted regularly with staff at CMTM and the EcoTarium to ensure that the prototype exhibit was meeting the desired learning outcomes.

Findings

The findings from each round of prototyping helped us to make the interface more user-friendly. The first complication we faced was the movement of the arm. The initial movement was jerky and made it difficult for the visitor to use exhibit. This also prevented prolonged engagement which was our goal. With the help of flow control valves, the movement became much easier to control and the learning outcomes became more transparent. Once the arm was easier to control, it promoted prolonged engagement by providing the user with an open-ended objective based goal.

We also found that the difficult nature of the arm's operation was a perfect attribute to promote parental and peer involvement. Operational skills also drastically increased over time and once children had a mastery of the movement they had no problem walking other visitors through the process. With the introduction of an objective based game, these outcomes increased, gave the exhibit direction, and expanded on the user to user interaction.

Our final major finding was that we would need to develop displays to assist with the exhibits use. These signs provided visual instruction as to the function of each component of the user interface. Additional displays explained to the parents the scientific concepts at work which they could them explain to their children.

Conclusions and Recommendations

From this prototyping we learned much about the exhibit design and evaluation processes. As for these evaluation methods, we found that design criteria and desired learning outcomes are essential to establish at the beginning of the design process. These learning outcomes must not be too specific however, because it is very difficult to design to a specific learning outcome due to the different perceptions users may have of the exhibit. We also found that prototyping on the floor must occur as soon as possible since it is an invaluable way to gain essential information directly from museum visitors. Through this prototyping, we found that gradually improving the exhibit's design proved easier to analyze and determine which changes were useful. Debriefing and analyzing the prototyping session as a whole after the fact proved useful for connecting the group's thoughts and observations of the day.

Our recommendations moving forward with our specific exhibit would be to first fully enclose the exhibit to prevent children from reaching around. We would also recommend further developing the diagrams and displays to assist the users in their experience. Finally we recommend creating ways to make the technology more apparent whether it is through magnetic tic-tac-toe pieces or making the airflow direction apparent. As a sum of our project, the CMTM has a working prototype that engages visitors, promotes family learning, and connects them to engineering concepts.

Authorship

This report was written by all four group members: Audrey Blasius, Jerrod Heiser, Katelyn Puttre, and John Stackable. We divided tasks as needed, however most hands on work was done as a group. Although most sections of the report had one primary author to begin with, each member of the group read and edited everything equally to ensure accuracy.

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Shift from Didactic to Constructivist	Audrey Blasius
Child Development	Katelyn Puttre
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Conclusions	Katelyn Puttre
Recommendations	Audrey Blasius

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I. Introduction

In the United States museums attract more than 850 million visitors each year, this is more than six times the number of people that attend every major-league baseball, basketball, football and hockey game in a typical year (Mondello, 2008). As this statistic indicates, museums are popular, but they strive continually to remain relevant in a changing world so they can achieve their primary goal of education.

In the past, museum exhibits were designed according to curator preference rather than to meet the particular needs of audiences with different interests. Typically, a museum might include numerous static displays of artifacts from the museum collection with interpretive text panels and labels. Over time, museums began to shift to incorporate more interactive, hands-on exhibits that research shows are more engaging and educationally effective. Science museums and children's museums in particular have been on the cutting edge of the changes in exhibit design and approaches to informal learning, although art, history, and other museums are adopting many of the same strategies. Given the nature of the audiences at science museums and children's museums, they have placed special emphasis on family learning.

The Philadelphia Informal Science Education Collaborative (PISEC) identified seven characteristics, that if present could increase family learning in an exhibit (Borun, 1998). These characteristics are: multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant (Borun, 1998). While these characteristics do not constitute all that is needed in a family exhibit, the PISEC research showed they markedly increased family learning. Evaluation methods have evolved and enabled the ever-changing world of museum exhibits and have been developed by numerous museum experts over an extended period. The Exploratorium has developed and promoted the concept of Active Prolonged Engagement (APE), based on their research showing that exhibits that engage visitors actively for extended periods are better able to promote learning (Tisdal, 2004). The APE studies recognize four different types of engagement and methods to measure how effective an exhibit is at achieving these forms of engagement. These different forms of engagement are Physical engagement, Social engagement, Intellectual engagement, and Emotional engagement (Tisdal, 2004).

Smaller museums try to build better exhibits using evaluation and the design guidelines and learning outcomes research, but lack the resources, collaborations one way around this limitation. The XLab collaboration, including the EcoTarium and The Children's Museum and Theatre of Maine intended to develop in-house capabilities in evaluation and exhibit design in order to meet the desired learning outcomes more effectively.

We used the same design guidelines identified by the APE and PISEC research to further develop a robotic arm exhibit that promotes family learning and interactive engagement. This exhibit must achieve the learning objectives that The Children's Museum and Theatre of Maine (CMTM) has envisioned for it. We used studies of families that use the exhibit as well as feedback collected from the museum staff as our main source of data. We have developed the exhibit and test the robotic arm prototype at the EcoTarium museum in Worcester, Massachusetts. Depending on the results of the test and feedback from visitors and museum staff, we evaluated the success of the prototype using visitor and museum staff feedback, as well as observations of visitor interactions with the prototype. We subsequently, adjusted the exhibit as necessary and retested the revised prototype until we found it met CMTM's desired learning outcomes. In the following chapter we outline how we achieved our goals.

In chapter II of this report, we outline the background to this project and the relevant literature on exhibit design and evaluation. In chapter III we describe our methodological approach to the robotic arm exhibit design, detailing our design and evaluation approach. This is followed by IV, our findings chapter, where we describe the changes of evaluation process, our discoveries from prototyping, and our conclusions. Chapter V summarizes our recommendations for further work in this field.

II. Background

It is important to look to the past to see the evolution and progression of museums when developing an exhibit. Many studies have determined the criteria which make an exhibit successful in the aspect of family learning. From these studies, methods have been produced which evaluate these exhibits. In section 1 we discuss the changes in the museums over time. The evolution of learning styles is presented in section 2 followed by a comprehensive explanation of the general and ongoing shift from a didactic to a constructivist approach in museum education. In sections 4 and 5 we discuss interactive exhibits and the exhibit design process respectively. In section 7 we outline different kinds of evaluation. Finally, in section 8 we present an overview of how exhibits are developed in museums.

1. Overview of Trends in Museums Changes

Museums have adapted since their beginnings in order to cope with changes in learning style, visitor demographics, and society's perspectives about activities considered to be most enjoyable. They continue to recreate themselves while trying to define their role in society. In the following section we discuss the evolution of museums learning outcomes.

1.1 Museum Shift

Museums of the early twentieth century generally served as a display site for interesting objects and historical artifacts. Children's and science museums began to shift away from such didactic displays and towards exhibits which appealed to and engaged a larger audience while introducing new topics. This shift began to take hold in the 1970s when museums started to incorporate visitor-centric behaviorist and constructivist approaches to exhibits and programs. These hands-on displays and visually appealing exhibits contained less text and consequently appealed to a diverse audience. Each individual museum's reaction to the new interactive style is different when it comes to how and when they changed, if at all. This is impacted by the resources available, mission of the museum, and the opinions of those involved. Even today, museums continue to evolve in an effort to remain relevant and attractive to visitors.

In the 1980's there was a shift to more guided discovery in the museums. The idea of guided discovery takes learners through a logical step-by-step series of discoveries towards a predetermined goal (Shaw, 1999). In problem solving, learners take their own path towards discovery and are free to make decisions about the subject matter. In the individual learner-designed program, learners pose problems and pursue solutions independently (Shaw, 1999). It is important that visitors can understand the text; they could in fact pursue their own independent inquiry. The innovation of both guided discovery and problem solving has had a positive impact on the design of museum exhibits. Along with Shaw, other studies such as Hein have looked into the inquiry-based learning which is outline in section 7.

2. Evolution of Approaches to Learning in Museums

Learning in a museum is very different than learning in a classroom. Although educators are now more aware of Gardner's (Gardner, 1991) multiple intelligences, which bring more senses into the learning process and incorporates more movement. Using the knowledge that all children learn differently and therefore adding in more aspects of visual, musical, interpersonal, intrapersonal, linguistic, logical, and kinesthetic aspects into their exhibits helped create more interactive hands-on exhibits (Gardner, 1991). Connelly and Clandinin together wrote in *Teachers as Curriculum Planners* that it is "more important to understand what people experience than to focus simply on what they do" (Connelly and Clandinin, 1988). As museums recognized that children learn differently and that people come to museums for different reasons, these museums realized that they needed to cater to all these different styles and needs by having a variety of exhibits. The desire for more experiential learning makes field trips to the museum a great opportunity for a child to engage in interactive learning. This is accomplished by looking at and touching an exhibit to inspire the child to try something new. (Falk and Dierking, 2000).

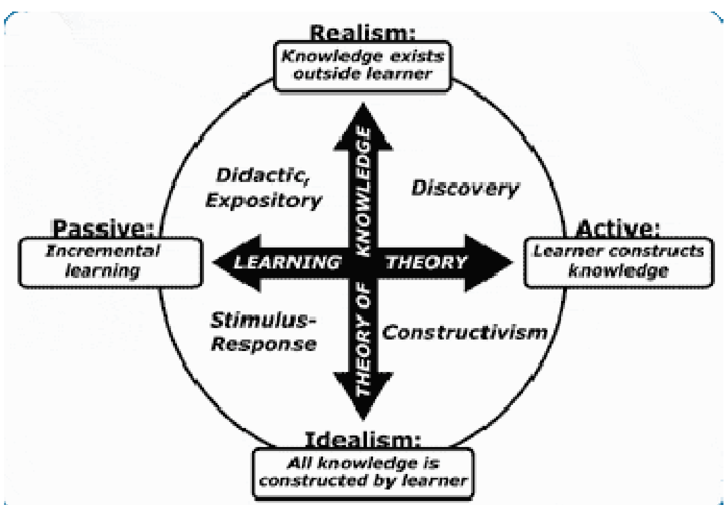

Figure 1 Hein 1996

3. Shift from Didactic to Constructivist

The style of learning in museums has been changing constantly to accommodate the learning capabilities of its visitors. This sweep from didactic to constructivist has broadened throughout museums over time.

Families have many options for activities that they can choose to participate in which range from anything from going to a movie theater to visiting a theme park. Also with advances in home theaters, video games, and computers, there are more reasons for a family to stay inside their house rather than leave to find entertainment. These are all factors which a museum must compete with to gain the attention of the public.

Even with other options, museums are still successful due to the role they play in society as a place of learning. “There is an element that interactive learning brings to the table that conventional teaching or informational videos cannot reach”- Rachel Blasius, elementary level educator. This feeling that museums can reach children through a different approach to learning about the real world is the main pull that brings in visitors. Along with the interactivity and thrill that some museums can bring to the visitors, parents and teachers attempting to educate their respective children realize this important form of learning and the benefits it can bring about. This form of family entertainment and education was made evident to the group when visiting the CMTM. Families were observed interacting and enjoying the exhibits which they were using.

4. Child Development

Children’s development is important to take into consideration when creating a children’s museum exhibit. Children’s museums have a typical audience age range from newborn to eight years old (Roberts, 2010). Over this age range, a lot happens in a child’s growth and development.

4.1 Developmental Stages

Not all children develop at the same rate, but typically children start to play with simple toys and play pretend games like house and other open ended imagination based games by age too. Children ages three to six begin developing the capability to learn on their own or work together with minimal conflicts with each other. Between ages four and six, they start following simple rules easily. Then around age five, the child’s mind becomes more project-based and a child may play out scenarios with cause and effect. This transition leads into the child starting to understand the reasoning behind rules and start to question them and take more risks. This age of experimentation is crucial since things the child tries more intuitive things. However, they find criticism brought about by failure difficult to take and this impacts their decisions going forward. It is important for museums to pay attention to these developmental stages in order to positively impact children and spark, rather than stunt, curiosity with their exhibits (Museum, B. C. s. M. C. C. s., 2010).

As children get older, their questions become more elaborate focusing on “what” questions at age two, moving on to “why, when, and how” questions by age five. As the questions get more intricate, the answers do as well; and by age five, the answers to questions become affirmative sentences opposed to an irresolute response (Museum, B. C. s. M. C. C. s., 2010). More importantly the child starts searching for knowledge around this age.

Many science centers and other museums are committed to designing interactive exhibits as an effective, fun, and compelling educational medium. It has been seen that each exhibit has its own optimal set of interactive features. For instance, too few and the exhibit fails to engage visitors, but too many and the experience is perplexing, troublesome and can then become unapproachable. After this balance has been achieved, children would be excited by and naturally feed off of such exhibits.

4.2 Learning Stages

The stages of learning that children go through are outlined by Piaget’s four stages of intellectual development. Piaget was a psychologist and expert on cognitive development and child education and his views have been widely regarded. The designation of these stages; Sensorimotor, Preoperational, Concrete Operational, and Formal Operational, help educators determine the best way to teach a specific child (Benaroch, 2005). Granted every child grows and develops at a different pace, each goes through these stages in order within a relatively predictable window of time (Baldwin, 2011). Without accounting for the adult visitors, children’s museums have a typical audience age of newborn to eight years old which makes the setup of their exhibits more focused on the sensorimotor and preoperational stages, with a little bit of focus and aim on children who have reached the concrete operational stage (Roberts, 2010). The sensorimotor stage is when a child can only focus on what they see in front of them. Children test things out to see how they react by hitting them, shaking them, or putting them in their mouths. They still believe that things don’t exist if you can’t see them which is why peek-a-boo is such a common game for infants. By the preoperational and concrete operational stages, the child starts thinking things through reasonably which signifies their transition from intuition to logical reasoning. They start to focus on the outside world, not just about how the world relates just to them.

5. The Evolution of Evaluation

Museums have moved increasingly toward constructivist and behaviorist approaches to learning by designing and incorporating hands-on, interactive exhibits. To evaluate the success of this new style of exhibits, evaluators typically look at dwell times as a measure of the effectiveness of an exhibits, assuming that ‘time on task’ is a proportional and directly related to the engagement of the child and what has been learned. Museums adopted a new style of prototyping with more of a focus on trial and error. First, a working prototype would be developed to test the overall feasibility of the exhibit concept. Should the prototype pass the initial stages of testing, it then passes to the next phase of development where the remainder of the exhibit is developed and further refined, all along the way collecting feedback from museum visitors and staff alike. This process continues and repeats until a final piece is developed that is deemed complete enough to be left out as a stand-alone floor piece (Athorn, 2013).

In common practice, the evaluation process is split into 3 different parts: front end, formative, and summative. This divide causes the exhibit design process to become more structured and helps the process by which exhibits are designed by removing some of the guess work and adding to the process. Such modes of evaluation are especially important for smaller scale children’s museums. Since these museums do not have the resources to make expensive and significant changes to finalized versions of exhibits, it is more cost effective to conduct evaluations early on so they can identify potential problems and correct them earlier in the process. Front-end and formative evaluations can be used to help with these earlier corrections. A formative evaluation is an informal qualitative assessment of an exhibit where details of content are overviewed. A summative evaluation, which seeks to monitor educational outcomes, often for purposes of external accountability, can be used to determine the success of an exhibit in the public eye. It is expensive to setup a summative evaluation and any changes that are needed end up being very costly as the exhibit is in its final version; however the knowledge learned from these studies can be used when creating later exhibits (Hudec, 2004).

As evaluation methods developed, museums discovered that museum visitors spent more time at exhibits that were engaging and interactive. They also discovered that people tended to learn more and these hands on and interactive exhibits. With time, it was observed that interactivity can only be taken so far and that an exhibit that is too hands on (e.g. excessive use of computer monitors) is more often than not counterproductive and proves to be over stimulating and even over whelming for some visitors. PISEC and APE developed out of these new evaluation methods and grew out of a long history of evaluation and represent the culmination of years of research. The PISEC criteria focuses more clearly on design criteria while the APE guidelines are more geared towards the other end of the spectrum that focus on learning outcomes.

5.1 Active Prolonged Engagement

Active Prolonged Engagement (Tisdal, 2004) was a project whose primary goal was to change the role of a museum visitor from recipient of knowledge to an active partaker of the exhibit. The project was broken up into two stages, the development stage and then the evaluation phase. We specifically looked at the evaluation phase.

The evaluation phase consisted of analyzing over 30 exhibits on the basis of levels of engagement. These different forms of engagement are Physical engagement, Social engagement, Intellectual engagement, and Emotional engagement. Each individual visitor was treated as a unique case study for each exhibit. After each testing the APE team interviewed those willing to take an interview on their experience and these were shown in the results.

The end result of each individual case study assessed the levels of each form of engagement and compared them with time spent at the exhibit and also the visitor's demographics. A short synopsis of each case study was also provided with any information gained from the interview. In the overall analysis of the exhibit, the successes of each form of engagement, significant examples of engagement, success of the exhibit, and level of satisfaction were all outlined using the data from each individual case study.

This study gave a true basis for the evaluation of an exhibit and also, with examples of engagement given in the case studies, gave criteria for which an exhibit's success could ultimately be determined.

Following this discovery, in the late 1990's, the Exploratorium Renovation Initiative continued in the development of exhibits that encouraged a shift in authority from the museum to its' visitors—a shift from planned to self-discovery— which included the refurbishment of many of physical science exhibits (Gutwill, 2006). The Exploratorium project was marked by a systematic improvement in the strength of initial engagement at physical science exhibits. “We found that a refinement of both the physical and graphical features of these exhibits produced a more fluid entry point for visitor interaction” (Gutwill, 2006). This work was rewarding in its obvious effect on the visitors: they were now far less puzzled about what they were supposed to do with those exhibits and why those exhibits were on the floor in the first place.

5.2 PISEC

PISEC defined seven characteristics of a Family-Friendly Exhibit. They include multi-sided, multi-user, accessible, multi-outcome, multi-modal, readable, and relevant. These characteristics will be used as criteria to measure the success of the exhibit. A multi-sided exhibit should be easily observed so that families clustering around the exhibit can be active together. A multi-user exhibit will allow several people to use the exhibit at one time. This ties in with multi-sided in the fact that it will cause clustering but many visitors will be able to use the exhibit. If an exhibit is multi-user, it should also be accessible and allow for comfortable use by children and adults alike. A large hurdle in the design process will be creating an exhibit that is small enough for use by young children, but not so small that parents do need attempt to interact with their children. As a child leaves the museum, it is important to know if they have learned and are continuing to explore more in their mind. This aspect falls under multi-outcome which will show, through observation and interactions that the end goal of the exhibit is open for the user to determine at their own discretion. Having an exhibit be multi-modal is one of the main characteristics. This means that it will appeal to varying learning styles and levels of knowledge. The exhibit must also be readable; text will be arranged in easily understood segments. Even though most children will go straight to playing with the exhibit and a parent might read the text, the text placed around the exhibit must be clear nonetheless. Lastly the exhibit must provide cognitive links to visitors' existing knowledge and experience and relevant and can be seen in the table below (Borun, 1998).

Characteristics of Family-Friendly Exhibit	
Multi-sided	Family can cluster around exhibit
Multi-user	Interaction allows for several sets of hands/bodies
Accessible	Comfortably used by children and adults
Multi-outcome	Observation and interactions are sufficiently complex to foster group discussion
Multi-modal	Appeals to different learning styles and levels of knowledge
Readable	Text is arranged in easily-understood segments
Relevant	Provides cognitive links to visitors' existing knowledge and experience

Table 1 Characteristics of Family-Friendly Exhibit (Borun, 1998)

6. Learning Outcomes in Design Process

Evaluators have identified key learning outcomes and tools to measure these outcomes. From these learning outcomes exhibit developers help establish a museum's role in society as a source of informal learning and not only entertainment.

6.1 Examples of Learning Outcomes

Successful science programs build upon a child's past experiences, background, and theories learned and understood at an early age (Worth, 2003). A program should also be able to encourage a child to pursue their own questions, develop their answers and ideas, explore topics, and talk to someone about their findings. It is important that all children have access to science and technologies, and that it is something a children's museum is capable of doing. Learning to work with others is a skill that children can gain in an exhibit. It is important to make an exhibit not just for one child but to keep the parent or older sibling involved in the exhibit and the learning process. There are three types of play when it comes to learning about science; dramatic, exploratory, and constructive. Dramatic play happens when a teacher is interacting with them and the child is told the functionality of the item they are using. Exploratory play occurs when a child is trying to find out how to make something work or happen without any assistance. Constructive play occurs as a child finds a challenge of building something and goes for it (Worth, 2003). With these different types of play, one can see that there are many ways to keep a child engaged with technology through play.

This learning through play can also be translated to science museums. Exhibits, especially at a children's museums, are contextual and have props to promote role play which will bring up questions for the children and encourage them to reveal their thoughts about not just about the exhibit, but about the world around them once they leave to go home. The continuation of their inquisitive thinking starts conversations with their parents when they get home; therefore creating stronger ties between the parent and child. However in many cases this does not occur. In a study by Shine, Parent-Child Social Play it was observed that despite the attempt to make the grocery store exhibit encourage mutual play between child and parent, the parents attempted to teach concepts or guide the child decreasing the overall communication. In most cases it was observed that the parents were too grounded in reality (Shine, 2004). This shows that parental influence on a child's learning has a very strong input upon teaching their children the ways of the world. Children's museums then need to design their exhibits in a way that encourages involvement with the parent as another player and not necessarily a leader.

When a parent or teacher goes through a museum with a child, their role varies greatly depending on how they view what they are doing. "Their titles ranged from interpreter, nature interpreter, environmental interpreter, and naturalist to docent, educator, and gallery educator. In terms of what they thought they were doing, descriptions ranged from teaching to interpreting to guiding and facilitating" (Castle, 2001). The child goes around the exhibits and it is up to their guardian to decide if they are going to let their child run around and figure things out on their own, or if they choose to act as an interpreter for their child and explain what is going on.

7. Exhibit Evaluation Principles

The key to evaluating the success or failure an exhibit is having a rigorous and well defined method for evaluating what precisely a child learns and takes away from their time spent interacting with an exhibit. Evaluating what precisely a child learns from an exhibit can be hard to evaluate, but 5 major categories have been established to judge what a child learns. The categories include (1) awareness, knowledge or understanding (2) engagement or interest (3) attitude (4) behavior (5) skills and any other concepts that may want to be evaluated on an individual project basis (Friedman, 2008). Although generic and simplistic in nature, these five simple points can serve as building blocks to create a more specific means of evaluating the successes and shortcomings of a museum exhibit.

7.1 Awareness

The first point of this design process is awareness, knowledge or understanding. This is a measurable increase in knowledge of a scientific concept or knowledge (Friedman, 2008). The exhibit needs to have aspects that allow the children to understand the simplified concept at play. If the intended principle is not sufficiently designed for the target audience, the exhibit will become underutilized and little to none of the intended learning outcomes can be achieved. The author of *Learning in the Museum*, George Hein; a professor at Lesley Graduate School of Art and Social Science, Cambridge Massachusetts, categorizes this as “Control—the visitor has a sense of self-determination and control” (Hein, 1998). This means that the child has a comfortable enough understanding of the exhibit to maintain full control over the situations and fully grasp the concepts at play. An adequate understanding of the fundamental principles at work will allow for further investigation by the child and ideally lead to conversation back home where the parent can continue the learning process.

7.2 Engagement

Engagement or interest is the measurable increase or decrease of a child’s interest in the concept the exhibit is trying to convey (Friedman, 2008). This can also be categorized as “Play—the visitor experiences sensory enjoyment and playfulness” or “Curiosity—the visitor is surprised and intrigued“(Hein, 1998). With these two factors in mind, an exhibit must be properly designed to the target audience and maintain their attention. If an exhibit is not interesting enough to maintain the attention of the target audience, then no educational concepts or ideas can be conveyed in the museum environment. The exhibit must also not be only fun and games. It must be thought provoking and lead the users to ask questions, but also built in such a way to keep the attention of its users. If an exhibit is designed to be purely an entertainment piece, no learning outcomes will be achieved.

7.3 Attitude

A change in attitude is gauging the altered opinion of a child’s perception of the scientific topics or careers relating to the topic. This can be perceived as a newly sparked interest in some idea or concept exemplified by the exhibit. This altered attitude can also be seen as a change in “Confidence—the visitor has a sense of competence” (Hein, 1998). If the exhibit plays to the strengths of a child it can easily embolden the child to continue to explore the exhibit and in turn further their educational experience. A change in a child’s behavior is similar in nature to a change in attitude in that they are both reflected in the way that the child interacts with the exhibit and can be viewed as a change in a child's outward perception toward the specific topic. This is especially important for gauging success because topics "that are environmental in nature or have some kind of a health science focus since action is a desired outcome" (Friedman, 2008). This change is important when introducing new concepts to children because sparking interest in a new topic is the first step for further exploration. An altered attitude will also ideally lead to further education and learning back home which is the ultimate goal of any interactive museum exhibit.

7.4 Skills

While determining the awareness, engagement, and attitude of the child playing with the exhibit is important, another point to investigate is how the exhibit affects their skills development. Skills have a wider definition ranging between intellectual skills and social skills, and interactivity has a different effect on both.

7.4.1 Intellectual Skills

The measurement of skills not only evaluates newly acquired skills, but also older skills that the child may have had the opportunity to practice. Most importantly, it also includes a means to evaluate a child's ability to observe, classify, explore, question, predict, or experiment with the exhibit which is an excellent indicator that the child has a firm understanding of the scientific ideas and concepts at play (Friedman, 2008). The development of these skills is crucial for the future development of interest in various scientific fields.

7.4.2 Social Skills

Another aspect of skills to be observed is the development of social skills through interaction with not only the exhibit but also other museum visitors. This is done through "Communication—the visitor engages in meaningful social interaction" (Hein, 1998). The development of social skills is always an underlying goal of museums, and is developed through interactivity. So the need for an exhibit to be multi-user is crucial to achieve this goal. An exhibit that is multi-user also allows for a family member to be involved which then incorporates family learning into the process.

"In addition, through exposure to objects and designed exhibits, visitors can make new connections, expand their thinking to reach different levels of awareness, and change conceptions, despite the evidence that conceptual change is rare and difficult" (Hein, 1998). The exposure to these new elements and expanding a child's thought process to better incorporate learning is the ultimate goal of a children's museum and a crucial step when trying to introduce new learning topics to children.

8. Conclusion

The new visitor centric style of exhibit design has evolved over the past 40 years. This shift is especially visible in children's museums where exhibits are hands on and interactive. Evaluation of these exhibits has played a central role in this evolution by identifying visitor needs and interests and by encouraging museum staff to develop criteria for exhibit design and to contemplate desired learning outcomes more rigorously. Smaller museums like the EcoTarium and CMTM are trying to develop their in-house capabilities in exhibit design, development and evaluation. This project was intended to help in this process by assisting in the development and evaluation of a prototype robotic arm exhibit.

III. Methods

Our team's primary goal was to create a prototype robotic arm exhibit that meets the CMTM's learning objectives. Our primary project objectives were: (1) to clarify CMTM's desired learning outcomes for the robot arm exhibit, (2) to develop the design criteria that will ensure the prototype exhibit promotes the desired learning outcomes and meets the other design objectives, such as safety and accessibility, (3) to create a series of prototypes based on the design criteria, and (4) to test, evaluate, and refine the prototypes. Our successes and failures accomplishing these objectives will be used to develop recommendations for development and evaluation of future similar exhibits. In the following sections we describe each objective and explain our approach to achieving them.

1. Objective 1: Clarify Learning Outcomes

As indicated in the background section, museum evaluators, educators, and exhibit designers have identified a variety of learning outcomes for exhibits, that include increasing visitor knowledge, awareness, and engagement and enhancing physical and mental skills. Others have developed a mix of design and learning objectives, such as PISEC with its criteria for family learning (i.e., multi-modal, multi-user, etc.) and APE. We will review this material and elaborate about how it connects to our pneumatic arm prototype.

We had a series of initial discussions with CMTM and EcoTarium to clarify the learning outcomes and subsequent discussions at regular intervals during prototyping in order to check that the design was progressing appropriately. Aside from the desire to encourage children to be interested in engineering and to promote family learning, the discussion of learning outcomes ranged across a variety of topics to determine if the learning outcomes should focus on developing motor skills or knowledge and awareness of scientific concepts. We also discussed if the exhibit should encourage visitors to explore how robots, levers, and electro-magnets work, if it should encourage visitors to build robots or mechanical devices, or should it focus on how the arm can be used to engage in an open-ended game.

2. Objective 2: Develop Design Criteria

While we did not identify an explicit, written set of design criteria for the exhibit, we consulted with staff at CMTM and the EcoTarium to identify key attributes for the exhibit. The prototype exhibit has three primary parts: (1) the pneumatic arm; (2) the user interface (UI); and

(3) the interactive game/task/challenge. The basic design criteria for each of these parts were established during initial discussions with The CMTM and EcoTarium staff. The design ideas changed as the prototype evolved with feedback from the formative evaluation (see Objective 3). Essentially, the mechanical arm should be simple, 'transparent,' and clearly demonstrate the function of pistons and levers. Next the user interface should be intuitive, easy to use, and accessible to multiple users/family groups. Finally, the game/challenge should be age appropriate, gender neutral, and attractive to a wide variety of ages and audiences.

3. Objective 3: Create Prototype

The first step in the creation of an interactive exhibit was to fabricate an operational prototype. The prototype exhibit had already gone through several stages of evaluation and development at CMTM, so we began with a reasonably well-developed basic exhibit design; however more modifications were necessary for the prototype to be user-friendly and safe on the museum floor. In doing so we created a table-top base to keep the arm steady, moved one of the pistons to allow for a larger range of motion, built a Lexan barrier between the user and the arm, and created a user interface with levers, a switch, and a turntable (lazy Susan). The goal was to get the prototype on the museum floor for testing as quickly as possible and ensure user and visitor safety.

4. Objective 4: Test, Evaluate and Refine the Prototype

Once we had a prototype that was safe enough to have on the floor, we started the dynamic process of rapid prototyping and redesign. The prototype evolved through several rounds of testing, evaluation, and refinement at both the EcoTarium and CMTM. Each refined prototype involved placing the prototype on the museum floor, inviting visitors to interact with the prototype, and observing the interactions. Following discussion about the observations within the group and with EcoTarium and CMTM staff if necessary, we modified the prototype and conducted the next round of testing on the floor. Each prototype was tested by our team prior to testing on the museum floor to ensure safety and appropriate functionality.

An important step to the prototyping process is placement at the museum. We had limited options for location because the compressor was noisy and we wanted to be in an area with relatively high traffic. We observed that weekdays at the EcoTarium typically attracted mothers with young children, while older children and more fathers were typical on the weekend. We conducted testing on a variety of days to ensure a broader audience mix.

During testing, we quickly found that recruiting participants was seldom a problem. Visitors readily approached us to try their hand with the prototype and it appeared the robot/mechanical arm was intuitive attractive to children and adults. People were especially eager to try the prototype if they observed others already using it. We observed that the prototype was sufficiently intuitive to many children that we did not need to encourage parents/caregivers to oversee their participation.

4.3 Observation and Evaluation

During our first round of prototyping, the full functionality of the exhibit was thoroughly explained and then we allowed the child/children to play with the arm. While the user(s) used the prototype, two team members observed how the visitor group interacted with the prototype and recorded his/her observations, one from close up and another from afar. The notes from this round of prototyping were simple short hand observations. Once the arm was developed to a user-friendly prototype, we created a chart (Table 2) which gaged success based on the learning goals and background research. However, we did not use this chart moving forward, instead, we continued to use our same shorthand methods.

Subject Interest (check one)	Subject gives undivided attention	Shows interest but can	Subject is easily distracted	Subject shows little to no interest
Ability to use Prototype (check one)	Subject can use prototype with ease	Subject can accomplish prototype goal but with slight difficulty	Subject cannot accomplish goal but can still slightly operate	Subject cannot operate or accomplish prototype goal
Subject Emotion (check all that apply)	Overwhelming Enjoyment	Curiosity	Concentration	Anger
	Confusion or feeling lost	Disinterest	Frustration	Fear

Table 2. Original Prototyping Sheet

4.4 Guidance

We consulted regularly with CMTM and EcoTarium staff to collect feedback from the prototyping evaluations and how to proceed with modifications of the prototype, especially with regard to the overall goals of the exhibit. The staff was able to critique the exhibit better than the team due to their experience in the museum. They spoke from their expertise as to the advantages and disadvantages of the exhibit and helped point the team in the best possible direction to achieve the design criteria.

IV. Findings

This exhibit's prototyping stages started before our team began building. First we discuss this history of the arm's progress before we worked on it. Next we discuss the design criteria we used to develop it and test it. Finally we have a comprehensive explanation of our pre-prototyping setup followed by the details of our prototyping and what we discovered and suggest for future work.

1. Pre-Prototyping

1.1 Earlier Stages

CMTM conducted several iterations of prototyping and evaluation in order to develop the version of the robotic arm that is presently on the floor in Portland. The current version (Figure 1) uses several motors which move joints and causes the arm to move, but the multi-button interface is not intuitive, the arm is prone to failure, and the learning outcomes remain obscure. Neither children nor adults could easily manipulate the arm to achieve the goal of moving slices of imitation bread into the baskets, and the fundamental mechanisms of the arm were not readily apparent since the servos are essentially 'black boxes.' Based on early prototyping, the CMTM found that visitors could not easily understand electronics and technology since it was unclear how pushing a button caused things to move. After looking into other robotic arms and using their prototyping information, the CMTM decided it was best to try a more mechanical alternative. They made a crane-like arm with two pistons and two joints. This arm first started with two hydraulic pistons, but the hydraulic fluid was too messy for the museum setting and CMTM staff switched to a pneumatic system (Figure 2). Our team began the project with this version of the prototype. Through discussions with our sponsor Chris Sullivan and review of the relevant literature, the group began to define the learning outcomes more clearly. The overarching goal was agreed upon by the group to be a simple task as to not complicate the

Figure 2 Robotic Arm at CMTM

exhibit unnecessarily. As for the specific learning outcomes, our group and the CMTM had collaborated and agreed to create an exhibit that inspired children in engineering as well as promoted family learning.

Figure 3 Pneumatic Arm

1.2 Design Criteria

Based on our review of the literature we identified several key criteria that would shape our design process. In particular, we focused on the PISEC criteria to help us develop a family-friendly design, and the Exploratorium's criteria to develop Active Prolonged Engagement (APE). Our group had agreed to make the exhibit open ended and as multi-modal as possible and wanted the parent to assume a role of explaining the control and scientific concepts of the exhibit. Our group also wanted to create a multi-sided or multi-user exhibit.

These predefined criteria would be used to design and modify three main aspects of the exhibit. Firstly, the interface needed to fit these criteria in order to be used by the visitors and therefore had to be intuitive. This interface consisted of two valves, one to control each piston as well as a way to control the electromagnet. The arm itself had to be designed with these qualifications so the technology was transparent enough for a young child to understand. Finally, the game or task the arm would be used for had to be developed without forgetting that it needed to be open ended, engaging, and multi-user friendly while still being simple enough for a young child to play.

In addition to following the family learning criteria, the exhibit also needed to be constructed of cheap, durable, readily available materials. It also had to be safe since the arm is intended for use by children. Lastly, the design had to be compact so it could be moved easily for testing at the museums and ultimately would fit in the relatively small space (3ft by 3ft) designated for the final exhibit at CMTM. In addition to the arm itself and the user interface, we had to design a purpose for the arm – what was it that the visitor should do with the arm? Having observed other exhibits at CMTM, we decided that an open-ended game might be the best option and we explored what types of game best satisfied our design criteria. Some of these ideas included picking up a ball and placing it on a ramp, which would then roll it back to the original position. Other ideas included tic-tac-toe, a recycling game, as well as a shape stacking game. With these ideas in our minds, we decided to determine what characteristics would make our exhibit successful. We eliminated the ball and ramp game as it would take up too much space and be too costly. The stacking game was very one dimensional and not open-ended enough to foster prolonged visitor engagement. We chose to move forward with the two game designs of tic-tac-toe and the recycling game. From here, we moved on to the initial construction of the arm.

1.3 Mechanics

Before we could begin prototyping on the museum floor, we made several modifications to the basic prototype arm provided by CMTM in order to meet the design criteria above and improve its operation, usability, and safety.

The original electro-magnet used by CMTM was a very high voltage, and so to make the magnet work properly, we had to purchase a power adapter. Our group purchased an adapter, which allows for 12 volts dc and a current of .5 amps which is a very safe. The first modification made to the arm was to move the pistons into better positions to control the arm. The Figure 2 below illustrates the piston was moved from position 1 to position 2 and the wood at position 3 was resized and replaced with a stronger and more flexible composite material.

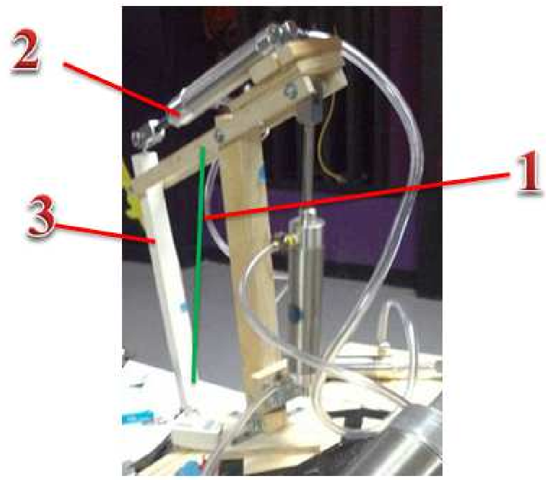

Figure 4 Arm Positioning

We mounted the modified arm to a plywood base, which could be attached to a table for evaluation on the museum floor. The original base as 3ft x 3ft, but this was cut down to 3ft x 1ft to allow for easier transportation. The narrower base also allowed us to insert a 3ft x 1ft panel for the different games.

Figure 5 Original 3x3 base before reduction

We mounted the arm on a “Lazy Susan” to allow the arm to rotate freely while not compromising its stability or safety. Once we had mounted the arm, we added the exhibit controls or user interface. Our group decided to mount the interface on three small plywood panels: one for the right valve, one for the left valve, and one for the light switch (see Figure 4). We mounted the light switch in between the other two panels to promote ease of use and because the left and right separation of the valves allows multi-user interaction. The separation may also aid in intuitive understanding of which valve controls which piston. We fixed these panels to the base at an angle to allow the exhibit to lie flat on a table. Angling the panels also made it more comfortable for people, especially children, to use the interface.

Figure 6 Interface panels fixed on a slant and valve and light switch layout

We attached the valves and light switch to the panels with screws as seen above in Figure 4. We sanded the valve handles and the panel edges for safety. With our interface created, we could now attach the tubing which connected the compressor, valves, and pistons. We first had to buy the appropriate amount and type of connectors (t-valves, elbows, adapters) to allow us to complete the "air circuit". The tube which connected to the compressor ran under the base to keep it safe and users were unable to tamper with it. This tube then split to each valve, each of which we connected to their respective pistons.

With our connections in place, we tested the system by inserting compressed air. Our compressor pumped air in at 150 psi, which proved too powerful for our arm's structure and moved the arm too fast. We reset the pressure to 10 psi, which made the motion of the arm much more controllable although the movement was still jerky. Our solution was to put in mechanical stops on the valve panels, which physically limited the valve range of motion which caused pressurized air to flow in a more regulated fashion.

Finally, we added a piece of Lexan to serve as a safety barrier (seen in Figure 5), with a slot at the bottom to allow users to turn the arm via the Lazy Susan. Since two members of the team were with the exhibit at all times when it was on the museum floor, side panels were not needed to ensure safety and visitors were instructed not to reach around the panel. With these exhibit modifications in place, we then moved into the prototyping phase.

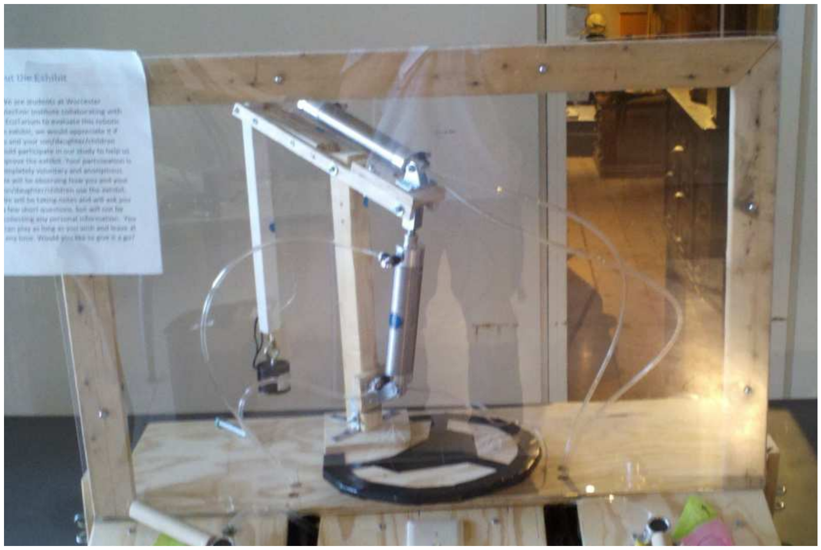

Figure 7 Lexan barrier

2. Prototyping

We conducted eight rounds of prototyping at the EcoTarium and one round at CMTM. During the course of prototyping we learned how to observe and evaluate visitors using the prototype, identified needed improvements in the design, and refined our expectations of learning outcomes. We evaluated approximately 10 to 30 visors at each round with the exception of the final two rounds, which due to the large crowds from school vacations had upwards of 50 visitors.

Round 1 (March 22, 2013)

For the first round of prototyping, the arm was set up on a table on the ground floor of the EcoTarium across from the pre-school area. This location had several advantages such as high traffic and visibility, as well as a place to store the compressor without the noise being too overwhelming. For this round of prototyping, none of the team members had any experience conducting exhibit prototyping evaluations, but it was soon apparent that the preset evaluation forms were too detailed for this stage of evaluation. Instead, we kept careful notes of our observations of visitors using the arm including strengths and weaknesses of the prototype's design, as well as important comments from users. In this version, Figure 5, however, visitors had a lot of difficulty controlling the arm due to the lack of pressure regulation, which made it very frustrating for users. Hoping to see if the interface we designed was intuitive, the arm was set up with no descriptions or instructions, but with a team member there to help children go through the steps as needed. We quickly learned that we needed to provide verbal instructions or cues to encourage participants to turn the wheel, turn the magnet on and off, and move the levers up and down to move the cylinders. The team quickly learned within a few users the shortcomings of the design and due to the difficulty to control the arm that children focused almost entirely on the function of the magnet rather than the arm, since it was the only aspect of the prototype that worked well. The arm had a very quick and jerky motion and tended to get stuck on itself.

Having identified a clear set of functional problems, we set about modifying the arm. The first issue to tackle was the arm's tendency to stick on itself and break. In order to fix this, we added blocks and stoppers were. Also, the top piston was swapped out with a smaller one to reduce the range of motion of the upper portion of the arm. The magnet's wires also tended to disconnect and to fix this issue, the leads were heat wrapped together as opposed to using less secure wire screws.

Once the arm was mechanically sound, the next concern was the motion of the arm. The first idea was to try to remove the compressor from the system entirely and have two pistons connected directly. We tried to connect the pistons to move with 1 to 1 correlation by directly pumping air back and forth between the two pistons. The thought process behind this trial was that children would better understand that their actions were controlling the arm as opposed to indirectly controlling the arm by manipulating air flow provided by the compressor. This worked well for a few minutes, however the system leaked and the pistons did not move as well as expected. After attempting to seal off the spots that were leaking, the team noted that the pistons quickly compressed the air and suffered the same problem as when the air leaked out. Since these attempts proved unsuccessful, we considered ways to incorporate the compressor to maintain the air pressure, but ultimately concluded that this method would not work either.

Increasing Arm Control

After continued brainstorming and experimental attempts along with additional research we found flow control valves that could make the movement of the air much more controllable. Unfortunately, these options were all expensive, too big, or made specifically for hydraulic instead of pneumatic systems. After much turmoil, we found a company that works exclusively with pneumatic systems called AIR Inc. that had all the supplies necessary fix the problem with the control of the arm. The AIR Inc. flow control valves are adjustable and limit how fast the air can flow out of each side of the pistons so that the motion is much smoother. The valves were designed for smaller gauge tubing, however, so from this point on all the fittings and tubes were switched to the smaller size for simplicity and consistency. By using the narrow gauge tubes we also had the additional benefit that the fittings incorporated a quick release function that made replacing and swapping tubing quick and easy. Our primary finding from Round 1 was that the arm was too jerky and hard to control so visitors got frustrated and focused more on the magnet function.

Round 2 (March 28, 2013)

With the modifications to the arm to make it easier to move and control, the team took the arm back to the EcoTarium for another round of prototyping. With the new valves installed, both children and adults were able to control the arm much more easily. This in turn reduced the observed levels of frustration substantially, especially among children, and increased time spent on the exhibit. Nevertheless, most participants needed further instructions as to how the levers controlled the arm. Once they received these instructions, most were able to use the arm easily and effectively to pick up and drop the bolt, which was still the only task required. At this point in time, we were still discussing the necessity of signs with our advisors and sponsors to explain the controls of the arm. We wanted to see if users could figure out the controls though trial and error and test how well of an exercise in problem solving the user interface proved to be. Once we had verified the necessity of the signs, we fixed them to front panel to note their effectiveness.

These diagrams, seen in Figure 6, allowed parents to visually perceive the controls of the arm and they then instructed and guided their children using this knowledge. The children would initially walk up and just wildly pull and push the levers, but once they actually tried to figure the controls of the arm, most children seemed to grasp the controls. If they did not understand, most parents would instruct their children and explain how each lever controlled different parts of the arm. Some parents would relate it to everyday life by juxtaposing the arm to a human arm by comparing different joints in the arm to a shoulder or elbow. Another father said to his daughter that the arm worked like the crane he operates at work and she

Figure 8 Handle Controls

immediately understood and expressed a new found enthusiasm for the exhibit. Another quick fix was adding a piece of tape to the magnet to limit residual magnetism so it will always release the object it is moving. Over time, the bolts tended to become slightly magnetized, so much so that the bolts would not drop even after the magnet was turned off. We also adapted our instruction style to focus more on the mechanics of the arm and its controls instead of the magnet. This proved to be much easier once the arm was easier to control. The children tended to focus almost exclusively on the magnet in the first round since the magnet was the only aspect of the exhibit that worked well. This new instructing method effectively highlighted the motion of the arm. The success of round 2 of prototyping showed us that the arm was ready for the next stage of prototyping which would implement objective based games. We decided on two games: a recycling game where cans are placed into a recycling bin and a tic-tac-toe game. The team also placed physical barrier to help limit the arm's range of motion so it would not get stuck on itself as often.

Figure 9 Round 2 Testing

Round 3 (April 4, 2013)

Our changes in the third stage of prototyping proved to be effective but this stage of testing also showed us a main problem with the arm which had not been addressed. The valves can direct air through one of two tubes or lock the system up. The connection the children were not able to make was that the valve's position was not reflective of the arm's position. We also noticed that the levers were situated in a forward and back movement orientation rather than up and down. This confusing orientation made it difficult for children to connect the levers movement with the arm's movement seen in Figure 7. This finding lead us to the understanding that the user interface needed to be more intuitive.

The solution to the confusing nature of the valve's operation was to use springs to push the handle to a position which was correlated with the "stop" position as seen in the picture above in Figure 8. Two springs were fixed to the handle and two barriers were set up on either side of the pivot point to make this happen. We also handled the left and right issue by re-attaching the valves to the base in a strictly vertical position so that all motion was up and down.

Round 4 (April 6, 2013)

These changes showed us some successes and failures in our fourth prototyping stage. The vertical positioning of the valves made it difficult for parents to see helpful directions and it also made the valves hard to reach. The springs proved useful but they were not as effective as we would have liked them to be at returning the valve to its neutral position. Our improvements started with the spring. The springs acted in compression, pushing the handle to its neutral position. We decided to flip the direction of forces by making the springs pull the handle back to the middle rather than push. Since the springs pulled in opposite directions with equal force, the resting position of the handle is in the middle which is perfectly in the neutral section. We also went back to our original valve orientation after considering other options. It was the most viable option which did not interfere with the vision of the visitor and worked reasonably well previously. In this round we also color coded the pistons, in Figure 8, to match their handles in an attempt to give a visual connection. This really did help and Parents were able to point out the connections to their children.

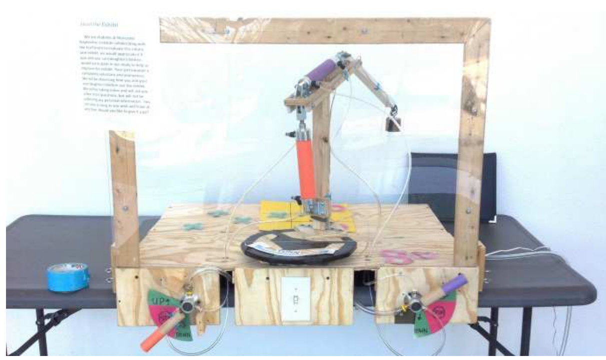

Figure 10 Color Coded Pistons, Handles Vertical

Round 5 (April 10, 2013)

Our fifth prototyping stage showed us that our new spring design worked as intended. We had to make minor adjustments to the panel which the valve is mounted to allow for maximum motion since the panels were too small right. Although the recycling game worked, it would need to be constantly 'reset' for the next user. The tic-tac-toe game however, entertained children regardless of how they find it, since children would take clearing off the board as a task as well. This achieved an open-ended game that fulfilled all the learning outcomes desired by the group and our sponsor. The game can be played and then after the pieces can be sorted and the simple thrill of picking a piece up is enough to get children's minds thinking. In this stage we also added a regulator to try and show the children that the air had a pressure, but it was not noticed.


Figure 11 Springs

Round 6 (April 12, 2013)

In this round of prototyping we fixed some of the labeling and added a more durable tic-tac-toe board. This new board was needed since the arm was ripping the board when it was made of construction paper and also added raised dividers between spots on the board to help guide the pieces into a section when they are dropped by the arm. This was a success and worked really well since children enjoyed playing the game and were able to get the pieces into the spots on the board much more easily.

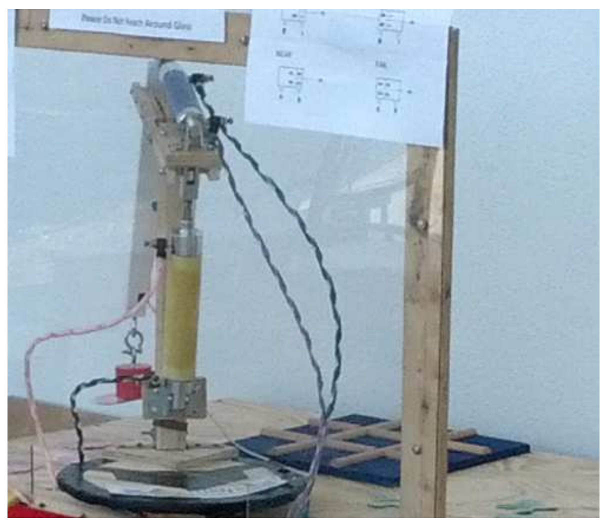
Figure 12 Tic-tac-toe

Round 7 (April 15, 2013)

In this stage of prototyping, we went to the CMTM to test out the exhibit in its intended home. Throughout the day, the arm moved through 3 locations. The day started set up in the CMTM's theatre room which made testing difficult since parents were not comfortable with their child being in a room with 6 other adults watching them. We then moved to an area with higher foot traffic. This gave us a much better audience and helped us determine that the audiences at the EcoTarium and CMTM were not really that different. Finally we moved to the very front of the museum and finished out the day there. After spending the day testing, we came away with more clarity on the learning outcomes. The overarching goal is to inspire an interest in engineering, but the specific subsets of that goal are to try to explain the topics and start the child questioning applications of pneumatics, electromagnetism, and help to foster and develop problem solving skills at a young age. Developing an interesting exhibit to accomplish these goals will lead to children asking questions in the future which allows for further parental and family learning which will ideally spark a long-term interest in various STEM topics. We chose these learning outcome subsets after discussions with Chris who participated in the day's round of testing. Through additional collaboration with Chris it was decided that in order to accomplish these outcomes the technology must be made more transparent by adding more color coding and labels so the children and care givers alike can easily make the connection between the controls and the movement of the arm. Additional prototyping for didactic displays that explain the function and application of pneumatics and electromagnets will be necessary to adequately explain the topics so caregivers can pass along the knowledge to their children.

Rounds 8 and 9 (April 18, 2013 and April 19, 2013)

Our last two rounds of prototyping at the EcoTarium clearly showed that the exhibit design was a great success. Our team sat back and observed the exhibit and found that it operated as well as when we had a host. The same longevity of use was achieved and the same level of recruitment was visible through the formation of a line to use exhibit. The multi user aspect was not lost either as the same cooperation and peer to peer teaching was observed. When we took a closer step we could hear conversations about the scientific principles and not just how to use an arm to play tic tac toe. The exhibit performed outstandingly and clearly inspired children all by itself and their use of it.

In these final prototyping rounds, we tested out some new signs that were developed to help the caregivers understand the pneumatics and electromagnet so they would stay longer at the exhibit and be able to explain these things to their children. These signs are in Appendix D. At this point in prototyping we sat back and watched the family interact with the arm with limit interference from us except in the case that a child was reaching around the glass.

Figure 13 Final with Signage

V. Conclusions and Recommendations

1. Conclusions

1.1 Prototyping

Throughout this project we have come to some main conclusions. First off, prototyping is an essential part of exhibit design. What seems intuitive to the exhibit designer may not be so obvious or intuitive to a visitor. Testing prototypes early in their development and observing users is the only way to assess this intuitiveness exhibit as well as any other limitations it may have. It is also important to test exhibit ideas as early as possible in the design process. Even if the design seems rudimentary, testing this with visitors allows for the design process to develop to the needs of the visitor and also avoids having the exhibit designer try to backtrack in the design process to find what causes issues for visitors. Testing a small number of changes sequentially and making incremental design changes is preferable since it is much less difficult to evaluate the effect of one change compared to multiple changes made at once. These changes are also then easier to spot and observation of fewer interactions between users and the prototype are needed before the next change can be made.

We have also noticed that recruiting for the robotic arm exhibit was relatively easy, in part because of the choice of location for the testing in the museum, but also because the arm seems to have an immediate 'attractive power' for visitors. As noted by the Exploratorium in their evaluations of APE exhibits, attractive power is one key element of successful APE exhibits. Using guidelines and studies such as APE and PISEC, we learned that the presence of two evaluators greatly simplifies the prototyping process, since one can play the role of recruiter and assistant, as necessary, while the other can be the observer and note-taker. Finally, Regular discussion and debriefing among evaluators especially discussions between evaluators in these different roles, during the course of prototyping is essential in the design and evaluation process. It is also important to continue this communication with exhibit designers and museum educators after discussions between evaluators. This process is necessarily iterative, but perspectives on design criteria, design options, and learning outcomes evolve dynamically.

1.2 Exhibit Design

Although we have not conducted a formal summative evaluation, we conclude that the exhibit design is quite successful based on our understanding of PISEC and other design criteria for the design of family-friendly exhibits. Our exhibit is intuitive to users and even relatively young children are quickly able to understand how to operate the arm and magnet with only little written or pictorial instructions. Left and right levers enable multiple users, and encourage peer-to-peer, sibling, parent-child interactions making the exhibit multi-user, and the variation in how people work together or guide each other while using the exhibit makes it multi-modal appealing to many different learning styles. The design of this user interface has also made the exhibit accessible to all ages since it can be comfortably used by children and adults. Some elements of the design may need to be more polished for final fabrication in order to become universally accessible, but the simple levers and switch should enable many visitors with more limited motor skills to access and operate the exhibit. This exhibit has also shown to be multi-outcome once a game was incorporated. Adding a game as simple as tic-tac-toe, encouraged peer-to-peer and child/adult interaction and we observed that the interactions regularly fostered group discussion about how the arm works, conversations about pneumatics and hydraulics, levers, and joints in the system through analogies to the human arm, as well as how the magnet works. These conversations occurred naturally and were increased through additional didactic panels.

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. It was especially attractive to visitors who first saw it already in motion through the use of another visitor. We also observed that the exhibit encouraged prolonged active engagement, since we had many subjects who stayed with the exhibit for more than 10 minutes and one who stayed for 45 minutes. Many of the arm’s visitors were found to leave for extrinsic reasons such as a parent cajoling the child/children to leave once they had decided it was time to look into other exhibits. The evaluators also noticed that visitors posed and answered their own questions, including ‘what if’ questions followed by exploration using the arm, and that they searched for and reflected upon causal explanations for exhibit phenomena. Finally, while we did not formally evaluate using the ACI 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. ‘Refueller’ was not really a relevant category, given the set-up of the exhibit as a prototype.

1.3 Learning outcomes

The robot arm exhibit is part of a larger exhibition designed to inspire children to have an interest in science and engineering, and the original design of the arm was intended to encourage visitors to explore the nature of robots, how they function, and what they can do. The various early designs experimented with different user interfaces to enhance the ease of operation, but the fundamental question remained what do visitors learn from the exhibit? 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.

A large problem the CMTM staff came across with the previous robot arm was that the basic servo mechanisms that make up the arm are intellectually inaccessible 'black boxes' to children which made it difficult for the staff to clarify what fundamental learning outcomes they intended the arm to promote. It is for this reason that CMTM staff moved back to a more simple design using first hydraulics then pneumatics. Building on this design, we have developed a prototype that meets many of the design criteria for a family friendly exhibit. The question remains, however, what are the fundamental learning outcomes of the prototype. Is the prototype designed to encourage the development of fine motor skills, which is one of the NSF impacts (Friedman 2008), or are the learning outcomes to encourage greater awareness, knowledge, and understanding of pneumatic pistons, mechanical levers, and electromagnetism?

From our experience, it appears that it is extremely difficult to clearly articulate in advance what the desirable learning outcomes of an exhibit should be. Indeed the learning outcomes may change during the course of exhibit testing and development, but it is helpful to have a goal learning outcome to strive towards. However, 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?

2. Recommendations

2.1. Exhibit Development

When designing an exhibit we recommend to first decide on the learning outcomes which are desired to be accomplished by the one exhibit. It is important to be very clear of what outcomes are desired beforehand and having them will make success easier to measure. We also recommend getting the prototype out onto the floor as soon as possible as to get the most information early on as possible. This stage lets you analyze the flaws present before further perfection is sought out.

As for the prototyping process itself, we recommend that for the first stage the users be as guided as possible. As the prototype is further developed, it is better to let the exhibit stand by itself and observe from a distance only intervening in cases where the exhibit fails. We also recommend taking note of the physical changes made to the exhibit. Also it is a good practice to determine what is being tested at each prototyping round and logging them to see how they change over time. Our post prototyping form as a whole we found to be very helpful and showed the full evolution of the exhibit and how we adapted the exhibit and our prototyping process throughout our project. We would recommend the same form to anyone testing a prototype exhibit in addition to their evaluation forms and post prototyping debriefing processes.

Throughout this process we have learned that it is very important to design exhibits that are designed to incorporate parental involvement. One way in which we recommend to incorporate parental involvement is to have an exhibit that is both exciting to parents but not intimidating. Finding a way to portray the exhibit so that it is intriguing to the child but not easily understood will cause the child to ask questions without instantly giving up. These questions are what provoke parental interaction. Another way to encourage parental involvement is to create diagrams that help the parent understand the exhibit which greatly increase the chance that they will assist the child.

2.2. Continuation of the Arm's Development

For continuation of this specific pneumatic arm exhibit, first we recommend fully enclosing the arm. There is currently a piece of Lexan in the front of the exhibit prototype that keeps children from reaching forward. However they can still reach around the sides if there is no individual there to prevent it. This is to ensure to safety of both the visitors and the exhibit itself. We also recommend continuing the prototyping process. Since we have not had the opportunity to fully test the didactics of the prototype exhibit we recommend testing different signs with variable quantities and phrasing of words to get better reactions from the visitors. Since we have determined the learning outcomes to be mainly scientific, different options for expressing the material should be explored. Some different aspects of the exhibit we think would be good to add information about would be how electromagnets work, how cylinders and pressurized air work, the physics of angles, and examples of each in the real world. These diagrams should be experimented with to determine the effectiveness of each at making the material and scientific phenomena more transparent to the user.

Along with these didactic displays of information, we recommend having small trinkets as side exhibit to provide assistance in understanding. One example would be a cylinder that the children can actually move and see into to decipher its function. A simple magnet station could also be created to highlight the fact that an electromagnet is present and to show how an electromagnet works.

Another solution similar to having side exhibits with the arm is to tie the exhibit into other similar exhibits in the museum it is in. It was noticed in the EcoTarium that people understood how air can move things better when we were next to an exhibit where air lifted things in the air. In the CMTM, the robotic arm will be incorporated into a pre-existing exhibit where it will be near a fan that turns motion into electricity. This sort of connection will be helpful for parents to describe how the arm works to their children.

As to highlight the magnet's function, we would recommend adding metal pieces to tic-tac-toe rather than having the paper pieces with washers taped between. This will undoubtedly give the pieces a metal look and make the magnets function as obvious as possible.

Finally, we would recommend cleaning the arm up a little more to make it more presentable. Possible enclosures for the handles would give it a nice look and new pieces for the arm itself could be used due to the number of holes in them currently. However too many improvements may take away from the unique look that it currently has which is a very industrial look which has proved to attract children.

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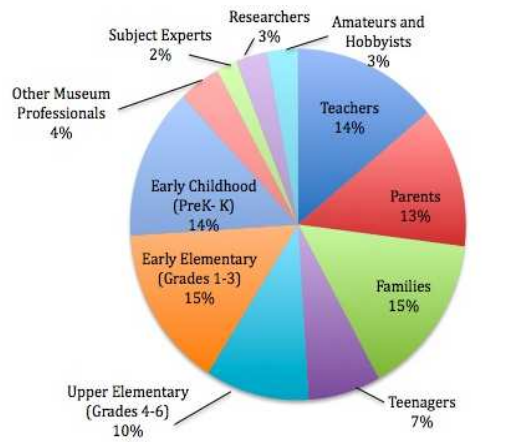
Appendices

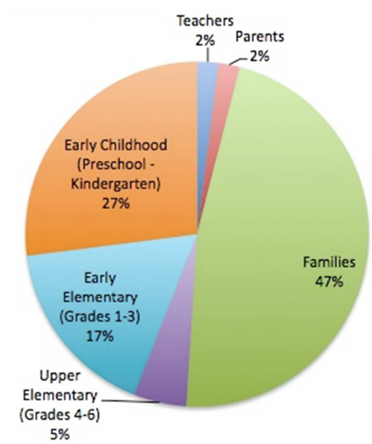
Appendix A – Children's Museums and Audiences

The role of science museums is not to throw information at people, but instead to encourage and inspire experimentation, thinking, and creativity. Castle, consultant and educator says that museums try to inspire people to learn, and subsequently share that knowledge. The exhibits have more recently become these constructivist, hands on, and engaging tool for learning (Castle, 2001). The tools for exhibition have themselves gotten more entertaining through the years. This includes child-oriented Exploratorium, cyber-museums on the Web, science on giant IMAX screens, and more (Mondello, 2008). All of these changes have made museums what they are today, drawing in 850 million visitors a year in the United States.

Of those 850 million, over 30 million of these visitors are children going to children's museums, specifically museums included in the Association of Children's Museums (A. o. C. s. Museums, 2008). These numbers show how important it is to know where the audience is going and what they are looking for. In the case of the EcoTarium and CMTM the target audience is mainly in this category of visitors. Before deciding on the level of interactivity and what kinds of engagements are necessary to build an interactive exhibit, it is important to be aware of the audience and its needs.

A study that surveyed museums found that "The largest audience segment is families with children in preschool-kindergarten (40 museums serve that audience). Grades 1-3 are also a major audience for children's museums (38 serve this group). In addition, over half (26) of the museums in our survey say they also serve upper elementary ages all the way through grade 6, and nearly a third of respondents (17) say they serve teenagers." (Roberts, 2010) The ages of these children span such a large age group, and yet it is still important to know the average visitor age and the guardians who come with them. "The Bay Area Discovery Museum, for example, has done an audience demographic survey and found their average visitor is age 4." (Roberts, 2010) The Children's Museum and Theatre of Maine and the EcoTarium are both aware of their average visitor ages as well as their adult audience being more females then males, and can therefore gear their exhibits toward their known audience (Sullivan, 2013).





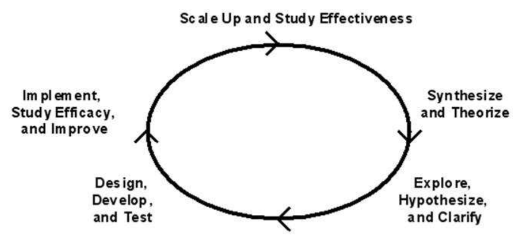
Audience Served (Roberts, 2010) Target Audience (Roberts, 2010)

Gender Tendencies

Major consideration should go to avoiding gender stereotypes such as girl's verse boy's toys. In the past, pink toys and Barbie's were designated to girls and boys had the option of building and cars. It has been observed that after the preschool age, boys and girls have a tendency to divide from playing together with Legos to their more gender-specific toys (Orenstein, 2011). Scientific fields have been slowly moving toward a more even distribution of genders, but it will also need help from parents to continue to break the stereotypes by bringing their girls into an engineering exhibit and not just think that is a boy's exhibit.

Appendix B – National Science Foundation

When designing an exhibit for National Science Foundation (NSF) the project begins with a hypothesis about how some aspect of Science, Technology, Engineering, and Mathematics (STEM) education can be incorporated into the learning and development process of the exhibit. It starts with a proposal that offers a plan for development with innovative resources, modeling, and studying of the innovation's impact of STEM learning. The proposal should express a plan of work that describes research and development strategies appropriate for attaining its goals. Proposals must demonstrate how the work is related to similar research and development (Plimpton, 2012).



Appendix C - Collaboration

Since smaller museums have more limited resources, a collaborative was created to bridge the gap in exhibit design and evaluation between large and small museum. This collaborative, also known as the Environmental Exhibit Collaborative (XLab), is made up of the EcoTarium in Worcester, Massachusetts; ECHO Lake Aquarium and Science Center at the Leahy Center for Lake Champlain in Burlington, Vermont (ECHO); the Children's Museum & Theatre of Maine (CMTM) in Portland, Maine; and The Discovery Museums (TDM) in Acton, Massachusetts. Each member has their own area of expertise. The EcoTarium has the largest design and exhibit fabrication capacity of the collaborative, whereas ECHO has the greatest number of hands on exhibits and specializes in the incorporation of computer based interactive exhibits. The CMTM specializes in the early childhood development and has educational programs for younger age groups (Worcester Natural History Society dba EcoTarium, 2013).

Comparative Resources between Museums

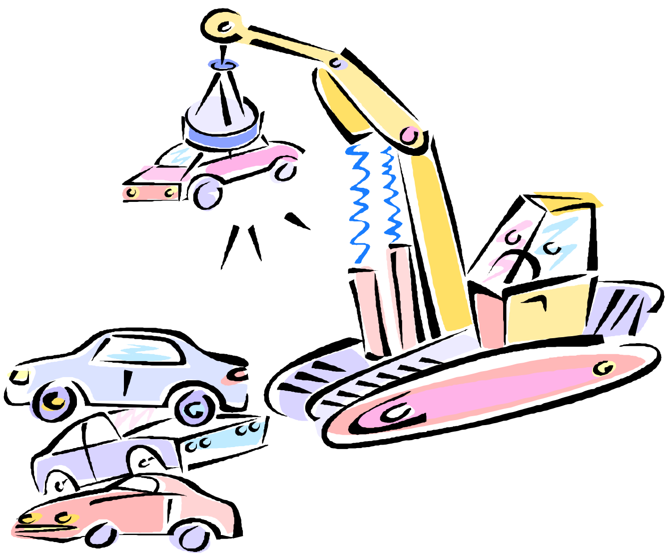
The design of exhibits requires knowledge and resources which vary in availability form museum to museum. These differences are mainly between large and small museums with larger museums having more resources and manpower than smaller museums. These differences between small and large museums and the comparative resource capabilities were the inspiration to create collaborations such as the XLab.

Some steps were put in place in the XLab contract that account for the differences between the members, workshops and team meeting were set in place. These two day meetings would be conducted 12 times per year to ensure open communication throughout the team. The first day of the gatherings are group collaboration meetings and the second day would be composed of presentations given by experts on the respective topics. This group based effort on exhibit design is an extensive form of brainstorming and should set an example for other museums to follow.

Appendix D- Signage

WHAT IS AN ELECTO-MAGNET?

An electro-magnet is like the magnet on your refrigerator back home, but can be turned on and off. It uses electricity to work and can be used for many everyday items.

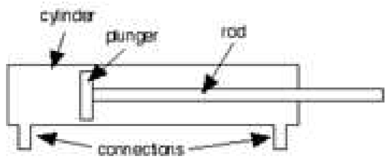


Magnetic scrap sorter seen in many junk yards

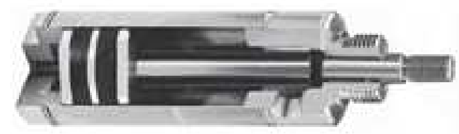
Without electro-magnets, we wouldn't have any speakers!

Because of electro-magnets, Disney World has this cool train called a monorail!

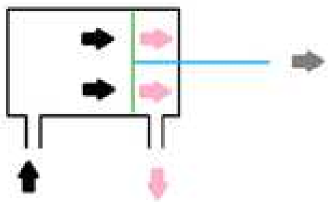
(Called a monorail because it only has one rail)



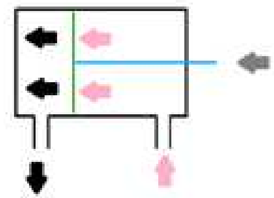
Pneumatics



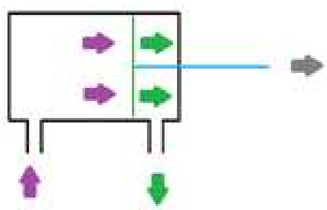
DOWN



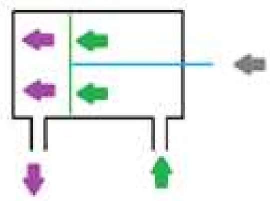
UP



NEAR



FAR



Appendix F- Example Prototyping Summary

Prototyping Round 1 – 3/22/2013

Prototyping Setup

Summary of exhibit - Main processes of the exhibit to be used. No posters or written instructions. Setup is two pistons both using the compressor and an electromagnet hooked up to a light switch.

Exhibit testing procedure – The main concept of the exhibit is to pick up a bolt using the electro magnet and to ultimately place it on top of a notebook. Jerrod is the facilitator and will assist users in the use of the exhibit. This testing will mainly test the functionality of the arm and children's ability to use it.

Testing results

Successes

- Magnet is wowing
- Multi user capable
- Long visit time

Shortcomings

- Controls are extremely difficult
  - Pistons act too fast
  - On/off valve concept not easily understood by children
- Magnet is overpowering and makes arms function not as interesting
- Arm gets caught up on itself
- Magnet holds objects with residual magnetism

Summary of testing – The way Jerrod brought children to the exhibit was first by demonstrating the function of the magnet by having the children turn the switch on and off and seeing the results. Then he assisted the children in the operation of the arm and told them what to do in order to accomplish the task of moving the bolt. The magnet was a huge draw in for the children but the operation of the arms mechanical pistons was a complete failure and they would not be able to grasp the concept on their own.

Suggestions

- Reduce piston speed to give greater control to the user
- Limit piston movement with manual stops to prevent "tangling" of the arm
- Cover magnet with some barrier to make objects drop more consistently
- Try observing the users rather than facilitating to see the exhibits standalone success