STRENGTHENING SCIENTIFIC LITERACY THROUGH LABORATORY EXHIBITS

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INTRODUCTION

Imagine a young girl visiting the New York Hall of Science for the first time. From the floor of the *Marvelous Molecules: The Secret of Life* exhibition, her eyes are drawn to a brightly lit, glass-enclosed space—the Pfizer Foundation Biochemistry Discovery Lab. Through the glass walls, she sees other visitors busy at work—actively engaged in experimentation. She thinks to herself, “I want to do that.” Entering the space, the girl looks around at the twelve tables covered with test tubes, centrifuges, droppers, and other tools. Families are gathered around the various tables, working together. The girl pulls her father to a vacant seat. The sign reads, “What Chemical Reaction Makes Cheese?” She begins to work—pouring real milk and vinegar into a glass tube and placing it in a centrifuge to see what happens. Her eyes bright with wonder, she exclaims, “You get to do the real stuff.”

In the last fifteen years, laboratory exhibits, such as the one described above, have been developed at several science museums¹ around the United States. These exhibits—distinct spaces that are accessible to the public on a drop-in basis, where visitors can use real scientific tools,

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¹ Today, there is little distinction between science museums (traditionally defined as object-oriented museums that have a collection) and science centers (museums based on experiences or phenomena, rather than objects). Both types of institutions today use hands-on, interactive exhibits and some science centers have even begun to develop collections. In this paper, the terms will be used interchangeably.
conduct experiments, and role-play as scientists—are part of an effort among science museums to involve visitors in practicing the process of science. Engaging visitors as active explorers and providing them with opportunities to interact with staff and scientific instruments, these experiences can empower visitors to see themselves as scientists who are capable of exploring the world on their own—a goal that has become increasingly important to science museums in recent years.

Laboratory exhibits have emerged, in part, as one response to very real concerns about the state of scientific literacy in the United States and, in particular, to concerns about a lack of understanding of the way science is used to make sense of our world. This lack of understanding of the scientific process—observing, forming hypotheses, experimenting, reaching conclusions, and repeating the process—reveals itself in many ways in our everyday lives. The following are just three examples of how a lack of understanding of the nature of scientific truth and of the scientific process is affecting our nation.

Across the nation, the early twenty-first century is seeing a growing movement to fight the teaching of evolution in public schools.

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2 This set of steps—commonly referred to as the scientific method—is a simplification of the actual process by which hypotheses become scientific fact. In their book, Laboratory Life: The Construction of Scientific Facts, Bruno Latour and Steve Woolgar describe a complex social process that involves proving to colleagues that one statement is more probable than any potential alternate statements. Scientific activity, according to Latour and Woolgar, is a “fierce fight to construct reality” (243).
Those leading the movement claim that evolution is a theory rather than a fact and should be taught as such. Dozens of states throughout the country are considering placing stickers in textbooks that state just that.3 This political strategy may be successful because the majority of Americans do not understand the distinction between a scientific theory—an accepted scientific principle supported by substantial evidence and tested by scientists, such as the theory of relativity—and the commonly accepted notion of a theory as an unsupported hunch. In fact, a 1999 study by the People for the American Way, a liberal, pro-democracy group, found that nearly three quarters of Americans believe that evolution is called a theory because it has not yet been proven scientifically.4

Each morning, thousands of Americans wake up and open the newspaper to check their horoscope. For many this may be simply a fun morning ritual, yet 40 percent of Americans believe that astrology is at least somewhat scientific.5 The presentation of astrology as a study based on science has led many individuals to accept this “pseudoscience” as a science—and to spend millions of dollars pursuing their knowledge of it—

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3 The proposed sticker reads, “This textbook contains materials on evolution. Evolution is a theory, not a fact, regarding the origin of living things. This material should be approached with an open mind, studied carefully, and critically considered.”
despite the fact that it is not based on scientific evidence. Similarly, each winter, Americans buy herbal supplements in droves, despite some negative side effects and the absence of conclusive proof that these supplements will reduce the likelihood of catching a cold.\textsuperscript{6} According to the National Science Foundation’s (NSF) report \textit{Science and Engineering Indicators 2004} nearly two-thirds of Americans do not understand the scientific process. This lack of understanding is resulting in growing concerns within the scientific community about potential adverse effects on our citizens’ health, safety, and financial wellbeing.\textsuperscript{7}

In recent years, schools have refocused their efforts on teaching the scientific process. The National Science Education Standards, which lay out what children should learn in school, have requirements related to learning the scientific process and developing scientific thinking skills for each grade level from kindergarten through twelfth grade.\textsuperscript{8} But, for many Americans who have completed their formal education, schools are no longer the primary place in which they learn. And, the formal school environment fails to meet the needs of many of our nation’s youth. Informal learning researchers John Falk and Lynn Dierking have


\textsuperscript{7} National Science Board, \textit{Science and Engineering Indicators 2004}.

determined that most Americans learn more outside of the school environment than within it.\textsuperscript{9} The vehicles for this learning are informal education sources—newspapers, magazines, the Internet, television, movies, libraries, and museums, among others.\textsuperscript{10} When individuals use these resources to learn, they are participating in what Falk and Dierking refer to as free-choice learning, or “the learning people do when they get to control what to learn, when to learn, where to learn, and with whom to learn.”\textsuperscript{11} Falk and Dierking have found that this type of learning can be highly effective.

Science museums are one of the primary vehicles for free-choice learning about science. A 2001 survey by the National Science Foundation found that 30 percent of Americans had visited a science museum at least once in the past year.\textsuperscript{12} And, the Association of Science-Technology Centers (ASTC) reports that its member institutions have a combined

\textsuperscript{10} The National Science Board’s \textit{Science and Engineering Indicators 2004} supports the finding that most learning—including science learning—takes place outside of the formal school environment. According to the report, most Americans gain information and news about science and technology through television (44 percent), followed by newspapers and magazines (16 percent each). The Internet ranked third, with 9 percent of Americans gaining information about science and technology through this resource.
\textsuperscript{11} Falk and Dierking, \textit{Lessons Without Limit}, 6.
\textsuperscript{12} National Science Board, \textit{Science and Engineering Indicators 2004}.
annual attendance of 83.3 million visitors worldwide. Americans also find museums to be a reliable source of information. In a survey commissioned by the American Association of Museums, 87 percent of Americans indicated that they found museums to be trustworthy, compared to 61 percent who found books trustworthy. Print and broadcast media and the Internet ranked even lower, with most Americans finding them untrustworthy. Clearly, science museums have the potential to have a broad and far-reaching impact on science learning.

But what impact can science museums really have in teaching the public the scientific process? Research has shown that science museums are not particularly effective at teaching specific science content or discrete facts. As such, we cannot expect visitors to science museum exhibits to be able to recite the steps of the scientific process or even necessarily articulate a definition of the process. What science museums have proven to be effective at, however, is providing visitors with authentic experiences in science. By directly engaging them in the scientific process, museums can provide visitors with a body of

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experiences that they can later build on to construct their own understanding of how science works. The more chances visitors have to engage in the process of science, the more likely they are to begin to understand the process and to be able to make distinctions between science and other epistemologies.

In recent years, science museums have begun concerted efforts to develop exhibits that engage visitors in the scientific process and develop their scientific thinking skills. In 1989, the Museum of Science in Boston adopted a new long-range plan that called for developing exhibits focused on the scientific process. In 1992, the Oregon Museum of Science & Industry opened *Engineer It!*, which presents visitors with design challenges intended to engage them in the experimental process—designing boats or airplanes, building bridges, and engineering building structures to withstand simulated earthquakes. And, in 1993, the Fort Worth Museum of Science and History opened *Whodunit? The Science of Solving Crime*, which was designed to teach visitors about the processes forensic scientists use to solve crimes.

Simultaneously, several museums were experimenting with laboratory exhibits. These too were designed to provide visitors with experiences with the scientific process. Some examples of these laboratory exhibits were the Science Museum of Minnesota’s *Experiment Bench*...
exhibits, which opened in 1991. These exhibits, located in semi-enclosed spaces, were designed to give visitors multiple variables to control and to allow visitors to design their own physical science experiments. A workbook published by the museum describes the process they hoped visitors would engage in as they explore the Experiment Benches:

We don’t expect visitors to pursue [the] experimental process formally in our experiment labs. We expect them to play with the apparatus and to try to see what’s happening. We expect that as they observe the phenomenon, they’ll start to say to themselves, “I bet that if I change this weight…” and then they’ll try it. As they experiment, we want them to develop simple, perhaps even naive hypotheses about how the phenomenon behaves and maybe even start to speculate why it behaves so.\(^{16}\)

Just a few years later, in 1994, the Oregon Museum of Science and Industry opened an innovative laboratory exhibit that allowed the public to participate in wet chemistry experiments.\(^{17}\)

A nationwide survey of science museums conducted for this project—an inquiry into the use of laboratory exhibits to engage visitors in the scientific process—shows that these exhibits have grown in popularity. In the survey, conducted in spring 2005 and completed by seventy museum professionals, 27 percent indicated that they already had a laboratory exhibit in their museum. An additional 49 percent indicated that


they are interested in developing one. And, although it was not a specific question on the survey, 13 percent of the respondents wrote that a laboratory exhibit was included in their future exhibit plans. In addition, representatives from twenty museums attended a recent workshop on the Science Museum of Minnesota’s Experiment Bench exhibits. Interest in laboratory exhibits is strong among science museums around the country.

As many museums are now developing or planning to develop laboratory exhibits, it has become increasingly important to formulate and disseminate a set of recommendations for how best to develop these exhibits in order to engage visitors effectively in the scientific process. In this project, I have sought to illuminate the educational and, to a limited degree, logistical issues to consider when developing a laboratory exhibit and explore the factors that make a laboratory exhibit successful. This project focuses on four different laboratory exhibit formats—wet labs, labs embedded in the context of a story, labs designed for frequent change, and open-ended exploration labs—and identifies the unique features of each of these formats. Through a survey of science center exhibit directors, interviews with exhibition development staff, examination of existing evaluations of laboratory exhibits, and informal observations of visitors, I have formulated a set of recommendations for exhibit developers.

18 Chris Burda, Senior Exhibit Developer, Science Museum of Minnesota, interview by author, February 4, 2005, St. Paul, MN.
interested in developing laboratory exhibits. Recommendations for exhibit
development focus on setting goals, selecting a format that best meets
those goals, designing the exhibit experience, and addressing
administrative issues. Through interviews with museum evaluators, I have
also developed a series of recommendations about how to evaluate these
types of experiences to determine their effectiveness at engaging visitors
in the scientific process. The evaluation recommendations explore the
need to develop behavioral objectives and conduct holistic evaluation—
encompassing physical, intellectual, and social engagement.

Research Questions & Objectives

A series of questions about the development and success of
laboratory exhibits drove my research. These questions, in turn, led me to
develop specific objectives which I sought to accomplish through my
research. The first question that I was interested in exploring is how and
why science centers have evolved in their focus and exhibits and how
science centers have historically used exhibits to engage visitors in the
scientific process. As I began the project, it quickly became clear to me
that the focus of science museums on teaching the scientific process was
something relatively new (emerging since the late 1960s) and I sought to
explore how this commitment came about. My specific objective was to
investigate the ways in which science center exhibits have changed over time and what research shows about developing effective exhibits.

In my research, I also sought to identify the defining features of the laboratory exhibit genre. When I began my research, I had a clear picture of what a laboratory exhibit was in my head. As I began to survey and interview museums professionals, however, my definition began to grow and expand, becoming much more nuanced as I realized that these exhibits can come in many different forms. My objective was to develop a thorough definition of this exhibit style that could encompass the range of formats that I found.

A third research question was to determine how many museums have developed or are planning to develop laboratory exhibits as well as what rationales exist for these types of experiences. I sought to understand the goals and objectives of science museums in developing these exhibits and to determine whether the goal of engaging visitors in the scientific process was one of the driving forces behind their development. My objective was to identify the museums developing these types of exhibits and assess their motivations.

I also sought to explore what, if anything, laboratory exhibits add to the visitor experience that is not provided in other ways. I was interested in both the educational and social impacts that these types of
exhibits have on the visitor. My specific objective was to investigate the successes and challenges of these types of exhibits through interviews, existing evaluation reports, and observations.

My fifth research question was whether and how laboratory exhibits are being evaluated to ascertain their effectiveness in terms of engaging visitors in the scientific process (as opposed to solely for their ability to teach specific scientific content). In addition to interviews with museum professionals and evaluators, I examined available evaluation reports to determine what they were assessing. My specific objective was to develop a set of recommendations for evaluating this exhibit style.

Finally, I sought to determine how to optimize these types of experiences to successfully engage visitors in the scientific process. Many museums state this as a goal of their laboratory exhibits, but it is very difficult to accomplish it. My objective was to develop a set of guidelines for exhibit developers about how to develop these types of experiences to ensure they engage visitors in the scientific process and increase their scientific literacy.

Methodology & Limitations

In order to complete the research objectives outlined above, I employed a wide range of methods, including a literature review, a
national survey, interviews, and site visits. The resulting methodology enabled me to gain a broad and robust understanding of my topic and the issues that underlie the development of these exhibits. My research provided me with historical as well as contemporary perspectives on the use of these exhibits in science museums and gave me an in-depth understanding of the educational theories that support their use.

_Literature Review_

In order to provide the necessary context for this project, I conducted a review of relevant books, journal articles, research projects, and websites. Topics that I researched include scientific literacy in the United States, the history of science museums and science centers in the United States, the evolution of interactive exhibits in science centers, existing research on exhibit effectiveness, relevant learning theories, and the evolution of discovery spaces in science centers (from traditional discovery rooms to laboratory experiences). The websites www.informalscience.org and www.museumlearning.com were especially helpful in identifying appropriate research studies and articles for review. Journals that publish results of studies into informal science education, such as _Curator, Informal Learning Review, Science Education, Journal of Research in Science Teaching_, and the _Journal of Museum Education_,
were particularly relevant to my research. The Association of Science-Technology Center’s publication, *Dimensions*, was also useful in identifying museums that have developed laboratory exhibits. Several books were also very valuable to my research including Victor Danilov’s *Science and Technology Centers*, which documents the history and evolution of science centers, and the ASTC publications *What Research Says About Learning in Science Museums* and *A New Place for Learning Science: Starting and Running a Science Center*, both of which feature research and recommendation for developing effective science museum exhibits. Reports from the scientific community have had a significant impact on recent efforts in both formal and informal education to focus on teaching the scientific process. Reports that I reviewed included *Science for All Americans* and *Benchmarks for Science Literacy*, both published by the American Association for the Advancement of Science. Several museum websites contain extensive information about their laboratory exhibits, particularly the New York Hall of Science and the Oregon Museum of Science and Industry, which were useful to my research as well. Finally, I also examined formal evaluation reports of five existing laboratory exhibits in order to identify trends among these exhibits. These evaluation reports proved to be an invaluable source of data regarding the educational impact of these exhibits.
In order to gain a broad picture of the use of laboratory exhibits in contemporary science museums, I sent a survey to 145 institutions in the United States that are members of the Association of Science-Technology Centers.\textsuperscript{19} To identify the survey recipients, I used a list of ASTC Passport program participants (these are ASTC member institutions that participate in a program of providing reciprocal admission to their members). From this list, I eliminated institutions that were not included in my scope (i.e., natural history museums, children’s museums, zoos, and aquaria). I also eliminated museums that have an extremely specific focus, rather than a broad science focus (museum of minerals, museum of surgical science, etc.) The survey was mailed to the director of exhibits (or other appropriate staff person) at each of the remaining museums. Seventy surveys (48 percent) were completed and returned to me.

I used the survey to gain a broad understanding of which museums have developed laboratory exhibits and when these were established, what types of experiences are being offered within the laboratory spaces, what the average budgets and staffing levels are, and what the broad reasons are for providing these kinds of experiences. Through the survey, I also sought to find out if these experiences are being evaluated for their

\textsuperscript{19} The full survey instrument can be found in Appendix B and summarized survey results can be found in Appendix C.
effectiveness at teaching the scientific process as well as, or instead of, their ability to teach specific science content. The survey also helped to determine what is deterring more museums from developing these types of experiences. Finally the survey served as a tool to identify individuals for follow-up interviews.

Interviews with Exhibit Developers and Evaluators in Science Centers Nationwide

Building on my survey findings, I conducted interviews with twelve exhibit developers (or other individuals who oversee exhibit development) who have worked on developing laboratory exhibits in their museums. I selected interviewees based on model projects I discovered in my literature review as well as the results of my survey. Discussion focused on descriptive information about the specific exhibits they worked on, reflective questions asking them to evaluate their specific projects, and general questions about the importance of these types of experiences and the impact on the museum field. I also asked the exhibit developers to provide recommendations to other museums interested in developing laboratory exhibits with the specific goal of engaging visitors in the

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20 A full list of interviewees can be found in Appendix D and a list of interview questions can be found in Appendix E.
scientific process. Four of my interviews were in-person while the remainder were conducted over the phone.

I also conducted four additional interviews (three in-person and one over the telephone) with museum evaluators who research the most effective visitor experiences in museums. My questions to evaluators were a subset of the questions for exhibit developers. I asked the evaluators to discuss characteristics of effective exhibits that engage visitors in the scientific process, challenges to accomplishing this goal, and the best ways to evaluate these types of experiences. I also conducted a final interview with a museum consultant who has worked extensively in the area of experience-based exhibits.

Site Visits

I conducted site visits to three museums that offer laboratory exhibits—the Science Museum of Minnesota (SMM), the Tech Museum of Innovation in San Jose, CA (the Tech), and the New York Hall of Science. The Science Museum of Minnesota was one of the pioneers in developing laboratory exhibits when its Experiment Benches first opened in 1991. Both SMM and the Tech have been recent innovators in the laboratory exhibit field, using computer guides to allow visitors to independently engage in complex experiments. And the New York Hall of
Science offers a picture of how similar experiences can be provided in a much more low-tech manner. At the first two museums, I was able to engage in the laboratory exhibits myself and informally observe other visitors to see how they interacted with the exhibit, the staff, and one another. At the New York Hall of Science, the laboratory exhibit was closed during my visit. However, at all three museums, I was able to conduct in-person interviews and see the laboratory exhibit spaces. Site visits gave me the opportunity to see first-hand how engaging, educational, and empowering these exhibits really are. In addition, the in-person interviews provided a richness and depth to my discussions that was more difficult to achieve over the phone.

Limitations

In order to focus my project and explore the areas of this topic of greatest personal interest, I chose to limit the scope of my research by geography, type of museum, and type of experience. Due to limited time and geographic constraints, I focused my research on science museums in the United States. With additional time and resources, I would have included laboratory exhibit examples from several international science centers. Most notably, Science North in Sudbury, Ontario, has developed a series of innovative laboratory and workshop spaces where visitors can
build and program robots using Lego® Mindstorms or engrave a stone in the Lapidary Lab, among many other activities. Findings from this and other international institutions may have enhanced this project or shed light on unique issues facing international museums. Nonetheless, the research that I was able to conduct through a literature review, survey, interviews, and site visits was robust. As a result, my findings and recommendations are applicable to science centers both nationally and internationally who are planning to develop these types of experiences.

While art museums, history museums, children’s museums, natural history museums, zoos, and aquaria have developed discovery spaces dedicated to exploring the processes of their specific disciplines, I am interested in how laboratory spaces can be used to promote scientific literacy. As described by Victor Danilov in his book *Science and Technology Centers*, science museums are specifically dedicated to explaining “scientific principles, technological applications, and social implications of these principles and applications.”21 Because of their specific focus on increasing science literacy, I decided to focus my research on science museums and science centers. A broader examination of laboratory spaces across the range of museums would surely have illuminated additional issues to consider, particularly with regard to age.

level and prior knowledge of audience members. However, this also would have shifted the focus of my paper away from the scientific process. As a result, similar experiences in art museums, history museums, children’s museums, natural history museums, zoos, and aquaria are outside of the scope of this project.

My research also looked solely at exhibit-based experiences. While many museums offer laboratory experiences as part of school or family programs (for which advanced sign-up or additional fees are required), I am interested in experiences which are available to all visitors at virtually any time and which have a much broader reach than a one-time family program or school field trip. Many museums also offer demonstrations, where visitors can watch as a staff member or volunteer conducts a scientific experiment. Because demonstrations do not allow visitors to have a hands-on experience with the scientific process and because they are only offered on a limited basis, I have not examined these experiences in this project. However, my findings and recommendations may well be relevant for program and demonstration experiences, as well as exhibits, allowing a broad audience of museum professionals to make use of these conclusions.

Finally, because my particular interest is in experiences that engage visitors in the scientific process, there may be other aspects to
laboratory exhibits that I did not explore in depth. For example, I did not
look at the effectiveness of these exhibits at attracting female as well as
male visitors. Several of my interviewees mentioned that their exhibits are
popular with girls or were designed with the specific goal of serving girls,
but I did not explore this feature in much depth. Additional research into
this topic would be worthwhile to conduct in the future. Furthermore, my
focus is on educational issues, with only limited discussion of logistical
issues, such as how to finance, set-up, or maintain these exhibits.

In addition to the choices that I made to limit my research by
gEOGRAPHY, type of museum, and type of experience, my research was also
limited by geographic, financial, and time constraints. If I had access to
additional resources, I would have attempted to see first-hand all of the
laboratory experiences that are featured in my paper and to interview
visitors about their experiences at all of these exhibits. Furthermore, with
more time and access, I would have conducted my own formal evaluation
of a laboratory experience. My findings are currently based on already
existing evaluations. Several of these evaluations did not examine these
experiences from the perspective of engaging visitors in the scientific
process or only looked minimally at this aspect of the experience, which
limited my ability to assess the effectiveness of these exhibits for this
specific purpose. Despite these limitations, my literature review,
interviews, limited site visits, and survey have provided me with a wealth of information about these types of exhibits. As a result, my project will contribute to the ongoing discussion of how to best engage science museum visitors in the scientific process.

**Product Description**

To disseminate the findings of my master’s project, I developed a proposal for a conference session at the Association of Science-Technology Centers’ annual conference. A conference session, which offers opportunities for working professionals to learn from others, is the best way to reach my target audience of exhibit developers, many of whom will be interested in talking to others about their experiences. Because my research focuses on science museums, ASTC is the logical conference choice, as opposed to a more general professional gathering, such as the American Association of Museum’s annual conference. Panelists will represent a wide range of museums that have already developed laboratory exhibits and will share their experiences and recommendations. An evaluator will also serve on the panel to provide expertise on how to evaluate these types of exhibits.

A conference session is the optimal method for disseminating my findings because it provides opportunities for interested museum
professionals to hear first-hand from those who have developed laboratory exhibits and to ask their own questions. When embarking on a new, resource-intensive project, such as the development of a laboratory exhibit, it is very valuable to hear from others who have experience with this type of project. The number of museum professionals who have requested copies of my master’s project (forty-seven) indicates that there is substantial interest in learning more about the development of these exhibits.

The Association of Science-Technology Center’s conference is the appropriate venue for my conference session. With over 540 members, ASTC is the world’s largest organization of interactive science museums. And, its annual conference is the world’s largest gathering of science center professionals. The 2004 conference, held in San Jose, CA, attracted over 1,600 attendees.\(^22\) I will submit my session proposal for the 2006 conference, to be hosted by the Louisville Science Center in Louisville, KY. A specific theme for the conference is yet to be selected; however, my conference session meets ASTC’s general conference goals. Fitting under the broad category of “learning strategies and theories,” my conference session will involve the audience, encompass multiple

approaches to solving a problem, and involve presenters from and
highlight more than one institution. The institutions represented in my
session are diverse both geographically and in size. The conference
session will provide opportunities for exhibit developers from around the
world and from a wide range of museums to learn more about the
educational potential of laboratory exhibits, the opportunities and
challenges, and the best way to evaluate these types of exhibits.

My proposed conference session, “Strengthening Scientific
Literacy through Laboratory Exhibits” features a panel of museum
professionals representing each of the laboratory exhibit methods outlined
in my project—wet labs, labs embedded in the context of a story, labs
designed for frequent change, and open-ended exploration labs. I will
moderate the panel, providing an introduction and summary. Presenters
will be asked to share their own experiences developing a laboratory
exhibit, the goals and objectives, the success of their exhibit in reaching
those goals, and advice that they would offer to other museum
professionals interested in pursuing this exhibit style. A handout will
provide a comparative analysis of the strengths and weaknesses of each
exhibit format. A museum evaluator will also be invited to participate in
the panel to provide perspective on how to best evaluate these types of
exhibits to determine their effectiveness in engaging visitors in the
scientific process. Attendees will also be able to ask questions of the panelists.

The session will also include a ten-minute opportunity for participants to engage in one of the activities offered at an existing laboratory exhibit, customized for in-seat use. Activities might include conducting an experiment to figure out how antacids work or determining what atoms are in sour foods, both adapted from the Pfizer Foundation Biochemistry Discovery Lab at the New York Hall of Science. This will provide attendees with the opportunity to see first-hand how the visitor experience at these types of exhibits varies from that provided at other exhibits.

Glossary

The following terms are used throughout this master’s project. The glossary provides definitions for any debated or specialized terms. Definitions apply only to terms as they are used in this paper.

Control:
In an experiment, a subject that remains untreated, as a basis of comparison for the treated subject.

Discovery Room:
Staffed spaces where visitors can have hands-on access to real and reproduced specimens and can engage in free exploration.
**Evaluation:**
In museums, studies conducted to gain a better understanding of the efficacy of an exhibition or program. There are three categories of museum evaluation. Front-end evaluation is conducted before an exhibition or program is developed to determine audience interest and prior knowledge. Formative evaluation, conducted as an exhibition or program is developed, tests the usability of components and their ability to communicate their message. Summative evaluation examines the impact of the exhibition or program on its audience.

**Evaluator:**
An individual who conducts evaluation studies.

**Exhibit:**
One component of an exhibition. In this paper, the term “laboratory exhibit” refers to a distinct space which may contain multiple activities.

**Exhibition:**
A three-dimensional presentation of objects or ideas, designed to communicate a message or provide an experience.

**Experiment:**
A series of steps carried out to test a hypothesis, determine an outcome, or illustrate an effect.

**Hypothesis:**
An assumption based on observation that can be tested through experimentation.

**Interactive Exhibit:**
Defined by exhibit developer Kathleen McLean in her book *Planning for People in Museum Exhibitions* as an exhibit that respond to the visitor’s actions. McLean describes them as exhibits “in which visitors can conduct activities, gather evidence, select options, form conclusions, test skills, provide input, and actually alter a situation based on input.”

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**Laboratory Exhibit:**
Distinct spaces that are accessible to the public on a drop-in basis, where visitors can use real scientific tools, conduct experiments, and role-play as scientists.

**Open Ended Exhibits:**
Exhibits which allow visitors to engage in multiple ways, to pursue their own questions, and in which there is no clear signal that the visitor has completed all the activities.

**Pseudoscience:**
Claims presented as scientific, even though they are not based on scientific evidence and cannot be proven through experimentation.

**Science Content Standards:**
An outline of what students should understand and be able to accomplish in each grade level from kindergarten through twelfth grade. There are both national science content standards as well as state-developed standards.

**Science Museum:**
A museum whose mission is focused on increasing understanding of science and related technology. Used interchangeably with “science center” and “science and technology center” in this paper.

**Scientific Content:**
Scientific facts, concepts and vocabulary.

**Scientific Literacy:**
Defined in many different ways but generally refers to understanding science at a level that allows the individual to understand science-related issues and make informed decisions as citizens. Typically includes an understanding of both basic science facts and the scientific process.

**Scientific Process:**
A simplified description of the process that scientists use to understand the world. Generally defined as a process of observation, hypothesis formation, experimentation, reaching conclusions, and repeating the process. In this paper, the term “scientific process” is also used to refer to individual steps in this process and does not always refer to the full cycle
of steps. Used interchangeably with “scientific method,” “doing science” and “experimental process” in this paper.

**Scientific Theory:**
An accepted scientific principle supported by substantial evidence and tested by scientists.

**Scientific Tools:**
Tools that scientists use to investigate and understand the world.

**Wet Science:**
Biology, chemistry, and other traditionally laboratory-based sciences.
BACKGROUND

The development of laboratory exhibits over the last fifteen years has been influenced by a wide variety of factors and trends in both science education and the museum field. Growing concern over the general public’s lack of both science content knowledge and an understanding of the scientific process has resulted in directives from several prominent national agencies—including the American Association for the Advancement of Science (AAAS)—that emphasize a need to change the way science is taught. These directives stress general scientific literacy over an understanding of specific disciplines, focus on the development of critical thinking skills, and advocate for teaching about the interdisciplinary nature of science.24 This change in focus from content to process has been embraced by informal education institutions, such as science museums, as well as the formal education sector. Museum professionals now realize that exhibits are not a particularly effective method of helping visitors acquire specific content knowledge. Learning within the museum environment is very different from learning in school, as visitors make choices about what to engage in or pay attention to, behave without receiving formal evaluations, and are influenced by the

environment and by other visitors. As a result, museums have little control over the specific content knowledge acquired by visitors.\textsuperscript{25} Despite this, museums can be very effective in increasing visitors’ comfort level with science and scientific ideas and providing them with hands-on science experiences that help them realize how science connects to their daily lives. Laboratory exhibits are one tool being used in pursuit of these goals.

Laboratory exhibits have their roots in discovery room exhibits—staffed spaces where visitors have hands-on access to real and reproduced specimens. Popularized in the 1970s by natural history museums, discovery rooms were quickly adopted by science and other museums. However, laboratory exhibits are also influenced by more recent efforts by several museums to develop exhibits that engage visitors in facets of the scientific process itself—observing, developing hypotheses, experimenting, and reaching their own conclusions. The development of laboratory exhibits not only springs out of a desire to teach science in a new way and to help visitors understand the nature of scientific truth, but also reflects recent research into the effectiveness of museum exhibits. A wide range of learning theories and ongoing exhibit evaluation provide support for the educational potential of laboratory exhibits.

Scientific Illiteracy in the United States

Scientific illiteracy\(^{26}\) in the United States is a significant and well documented problem. Numerous reports paint a dismal picture of the general public’s scientific knowledge. On a 2001 National Science Foundation survey measuring scientific knowledge, the 1,572 Americans surveyed answered an average of 8.2 questions correctly out of a total of 13. The survey revealed that less than 60 percent of Americans know that it takes a year for the Earth to travel around the Sun, over 50 percent incorrectly believe that humans and dinosaurs coexisted, and just 51 percent believe in evolution.\(^{27}\) The results of the 2003 Trends in International Mathematics and Science Study show mixed results in science knowledge among American students. The United States ranked ninth out of forty-five countries in eighth-grade achievement in science and sixth out of twenty-five countries for fourth-grade achievement. However, the gap between the United States and the higher ranking industrialized nations remains significant. Singapore, the highest ranking

\(^{26}\) Scientific literacy—or illiteracy—refers to understanding of both basic science facts and the scientific process.

\(^{27}\) National Science Board, *Science and Engineering Indicators 2004*. NSF notes that the percent of Americans who do not believe in evolution may reflect religious beliefs as much as lack of scientific knowledge.
nation, for example, boasts 44 percent of its students performing at advanced levels, compared to only 7 percent of U.S. students.28

This lack of scientific understanding has broad and far-reaching consequences. Our nation’s youth are leaving school ill-prepared for jobs in an economy that is increasingly reliant on science and technology. In 2004, the National Science Board announced that the United States is facing a shortage of scientists in the coming years. While the number of jobs in science and engineering continues to grow, increasing from 2.6 percent of total jobs in 1983 to 3.8 percent of total jobs in 2002, the number of Americans entering these careers is not keeping pace. Foreign workers have traditionally filled these gaps. However, increased difficulty obtaining visas and growing science sectors in other countries may mean that this option is no longer available.29

There is much debate about what comprises scientific literacy. The term “scientific literacy” builds on the concept of literacy as the acquisition and use of language. In his article “The Roots of Scientific Literacy: The Role of Informal Learning,” Jon Miller describes the relationship of the term scientific literacy to the more common usage of the word “literacy.” Miller describes basic literacy as the ability to read

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and write, while functional literacy refers to being able to read and write at a level that allows an individual to function in daily life. Drawing a parallel to scientific literacy, Miller describes basic scientific literacy as the ability to read and write about science, while functional scientific literacy is “a level of scientific literacy that allows a citizen to understand major public policy issues involving scientific or technology issues.”

Drawing a comparison between scientific literacy and literacy elevates the importance of scientific understanding, defining it as essential to functioning in daily life. In his article “Science Literacy and the Public Understanding of Science,” Benjamin Shen defined three types of scientific literacy—practical, civic, and cultural. These types of literacy refer, respectively, to being able to use science to solve problems, being aware of science issues in order to make decisions as a citizen, and being aware of science as a major human achievement. These definitions describe scientific literacy as much more than simply science content knowledge. Scientific literacy also essentially involves an understanding of the scientific process—how scientists use a process of observation, hypothesis formation, and experimentation to comprehend the world.

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However, according to the National Science Board’s *Science and Engineering Indicators 2004*, approximately two-thirds of all Americans do not have an understanding of the scientific process.\(^{32}\) This leaves Americans unprepared to fully participate as decision-makers, voters, or engaged citizens. As the report states,

> It is important to have some knowledge of basic scientific facts, concepts, and vocabulary. Those who possess such knowledge are better able to follow science news reports and participate in public discourse on science-related issues. An appreciation of the scientific process may be even more important. Understanding how ideas are investigated and analyzed is a sure sign of scientific literacy. It is valuable not only in keeping up with important science-related issues, but also in evaluating and assessing the validity of any type of information and participating meaningfully in the political process.\(^{33}\)

Since the late 1980s, the United States has been engaged in a systematic effort to improve science education. In 1987, the National Science Foundation instituted a $50 million initiative to improve science education at the elementary school level, providing funding for curriculum development and teacher training.\(^{34}\) This initiative sought to shift the focus of science education from content acquisition to understanding the scientific process. In announcing the 1987 initiative, NSF emphasized that the new curriculum would focus on experimentation and participation.

\(^{32}\) National Science Board, *Science and Engineering Indicators 2004*.
\(^{33}\) Ibid.
rather than memorization of scientific content.\textsuperscript{35} In \textit{Science for All Americans}, a 1989 report from the American Association for the Advancement of Science (AAAS), the authors clearly emphasized the need for the general public to understand how scientists think about and make sense of the world. And the report criticized the curriculum of the time as focusing far too much on memorizing specific content:

The present science textbooks and methods of instruction, far from helping, often actually impede progress toward science literacy. They emphasize the learning of answers more than the exploration of questions, memory at the expenses of critical thought, bits and pieces of information instead of understandings in context, recitation over argument, reading in lieu of doing. They fail to encourage students to work together, to share ideas and information freely with each other, or to use modern instruments to extend their intellectual capabilities.\textsuperscript{36}

The AAAS report clearly outlines a wide range of specific scientific concepts—in the areas of understanding the Universe, humans as a species, and other living things, among other topics—that all students should know. But, it also emphasizes the importance of understanding the nature of science, the process of scientific inquiry, and the scientific enterprise (encompassing the individual, social and institutional aspects of scientific research). It documents a need for students to develop scientific thinking skills, such as curiosity, openness to new ideas, and informed

\textsuperscript{35} Ibid.
skepticism, and for schools to foster positive attitudes about science.  

Finally, the *National Science Education Standards*, which in the last ten years have become the basis for science curriculum content standards across the country, “emphasize a new way of teaching and learning about science that reflects how science itself is done, emphasizing inquiry as a way of achieving knowledge and understanding about the world.”  

The standards, which built on prior AAAS reports, specifically outline that students in kindergarten through twelfth grade need to be able to understand the process of scientific inquiry with increasing sophistication, as well as develop the skills necessary to perform the process themselves.

While these directives and standards primarily address the formal education sector, science museums, too, can play an important role in introducing our nation’s youth to the process of science.

**The Role of Science Museums in Science Education**

Contemporary science museums have dedicated themselves to improving scientific literacy in the United States. This role for science museums first emerged in the late 1960s, when one of the nation’s first participatory, interactive science centers, San Francisco’s Exploratorium, opened. Prior to this period, science museums in the United States had a

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37 Ibid.
38 National Academy of Sciences, *National Science Education Standards*. 

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different focus. The earliest American science museums (which can be traced to the 1800s) were natural history museums, which promoted scientific research rather than education.\textsuperscript{39} Museum historian Steven Conn documents the relationship of research to early natural history museums:

As natural history developed in this country through the nineteenth century, it was deeply connected with museum work. The connection was a straightforward transitive one: the study of natural history depended on close, careful work with specimens. Museums existed to house and display specimens; therefore museums were the logical place to study natural history.\textsuperscript{40}

However, as the focus of science changed from specimen-based work to laboratory-based work, universities overtook museums as the locus of scientific research, and museums began to focus on the diffusion of knowledge, rather than its production.

The first American museums dedicated to science, technology, and industry, including the Museum of Science and Industry in Chicago, opened in the early 1930s. Early science museums were designed to celebrate scientific and technical progress and to highlight American industry.\textsuperscript{41} But, science museums began to change their focus after World War II as America put more and more of its resources into scientific

\textsuperscript{40} Steven Conn, \textit{Museums and American Intellectual Life, 1876-1926} (Chicago, IL: University of Chicago Press, 1998), 38.
\textsuperscript{41} Danilov, \textit{Science and Technology Centers}, 23-28.
research. The Boston Museum of Science was an early innovator in transforming the American science museum. It opened in 1950 and included exhibits that covered a broad range of scientific disciplines and that engaged visitors as participants, with objects to touch and machines to activate.42

But it was not until the Cold War—a time of dramatic tension and competition between the United States and the Soviet Union—that a significant change in science museums came about. The launch of the Soviet satellite Sputnik, the first man-made satellite, in 1957 resulted in a dramatic increase in fears about the Soviet ability to launch ballistic missiles and about the United States’ lack of scientific knowledge needed to respond.43 The success of Sputnik ushered in a period of science education reform in the United States. This reform was facilitated by NSF, which provided funding for a wide range of curriculum development.44 These political drivers also created an impetus for additional changes in the science museum, most notably the provision of direct experiences with science. In 1968, Frank Oppenheimer, founder of the Exploratorium, wrote of the need for a new kind of science museum—one where visitor-

controlled devices were supplemented by historical displays, rather than
the other way around. His words, now nearly 40 years old, still resonate
with many of the concerns about science literacy in our nation and the
justification for science centers today. He wrote,

"There is an increasing need to develop public
understanding of science and technology. The fruits of
science and the products of technology continue to shape
the nature of our society and to influence events which
have world-wide significance. Yet, the gulf between the
daily lives and experience of most people and the
complexity of science and technology is widening." 45

The Exploratorium, which opened in San Francisco in 1969, was truly a
new kind of science museum, with participatory exhibits and an
interdisciplinary focus, combining science, art, and human perception.
Oppenheimer sought to engage visitors in direct experiences with science,
to put visitors in the role of scientists, to empower visitors to feel that
science is part of everyday life, and to make science fun. 46

The growth of new science centers, such as the Exploratorium,
coincided with several changes in the museum field in general. The
American Association of Museum’s 1992 report, *Excellence and Equity:
Education and the Public Dimension of Museums*, emphasized the
educational role of museums. Chief among the mandates contained in this

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report is the directive to “place education—in the broadest sense of the word—at the center of their public service role.”47 In many museums, a shift also occurred from the traditional curator-driven exhibit development approach to a team-based one, which put a much greater emphasis on meeting audience interests and needs.48 Museums began to focus on attracting new audiences, partnering with community organizations, developing exhibits that are relevant and interesting to their visitors, and emphasizing customer service.49 These changes in the field influenced the development of science museum exhibits, spurring many of the more traditional museums to renovate their exhibits or create new ones designed to better serve their visitors.

Today, there are over 400 science museums worldwide, serving a combined total of 83.3 million visitors annually.50 Science museums have continued to transform and grow; some continue to look very similar to the Exploratorium with its loosely connected interactive exhibits while others have chosen to organize their exhibits along distinct and clearly

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50 Association of Science-Technology Centers, “Science Center Highlights.”
defined themes.\textsuperscript{51} Regardless of their organization, in many ways, today’s science museums still follow in the footsteps of the early science centers. They remain focused on scientific ideas and phenomena rather than objects, their primary mission is education rather than research, and they engage visitors as active participants in the exhibits.\textsuperscript{52}

In the United States, government, industry, and formal education all agree that science museums have an important role to play in improving science education and increasing scientific literacy. Between 1989 and 1992, for example, the National Science Foundation increased its funding for informal science education by 233 percent—from $15 million to $35 million.\textsuperscript{53} But, the exact role that science museums play in this effort and the aspects of science that museums are best equipped to teach are still under discussion. Research has shown that exhibits are not effective in teaching specific science facts. As evaluators John Falk, John Koran, and Lynn Dierking wrote in a 1986 evaluation of the learning potential of museums,

Unless the casual observer either has prerequisite knowledge, is directed to specific learning outcomes, or has specific learning intents of his own, it is likely that little

\textsuperscript{51} McManus, “Topics in Museums and Science Education,” 163-164.
\textsuperscript{52} Ibid.
learning of the exhibit content will result from the casual perusal of exhibits.\textsuperscript{54}

Rather than focusing on teaching science content, museum evaluators Mark St. John and Deborah Perry have argued that science museums should seek to help people “develop long-term relationships with the content, phenomena, and issues of science.”\textsuperscript{55} Research has shown that science museums can play several roles in strengthening these relationships. A 1994 literature review indicated that science museums can provide visitors with personal experiences with science, develop positive attitudes about science, show visitors how science connects to the real world, increase motivation and excitement about science, nurture a sense of curiosity and wonder, and provide opportunities for social interaction and shared experiences.\textsuperscript{56} The introduction to the 1992 Association of Science-Technology Center’s publication \textit{A New Place for Learning Science: Starting and Running a Science Center} outlines three additional contributions science museums can make to scientific literacy. The first is real-time access to science and scientists, including opportunities to ask questions of live scientists. The second is the chance to become comfortable with science, exploring without a fear of failure. Finally,

\textsuperscript{54} Falk, Koran, and Dierking, “The Things of Science,” 504.
\textsuperscript{56} Ramey-Gassert, Walberg III, and Walberg, “Reexamining Connections.”
science museums provide visitors with opportunities to gain first-hand experience with science, exploring and discovering on their own.\textsuperscript{57}

A study by Léonie Rennie and Gina Williams of the Curtin University of Technology in Perth, Australia, provides a concrete example of how science museums can play a powerful role in changing visitors’ attitudes about science.\textsuperscript{58} As part of their study, Rennie and Williams surveyed 102 visitors to an interactive science center in Australia, giving them both pre-visit and post-visit surveys to determine how the visit impacted their attitudes about science. Results of the survey showed the visit made visitors feel more positive about science and scientists, more confident in talking to friends about scientific topics, and more likely to think that they already use science to solve common household problems. Two-thirds of the visitors also cited ways the visit had caused them to think “differently or more deeply about science.”\textsuperscript{59}

\textsuperscript{57} Sheila Grinell, ed., \textit{A New Place for Learning Science: Starting and Running a Science Center} (Washington, D.C.: Association of Science-Technology Centers, 1992), 10-16.

\textsuperscript{58} Léonie J. Rennie and Gina F. Williams, “Science Centers and Scientific Literacy: Promoting a Relationship with Science,” \textit{Science Education} 86, no. 5 (2002).

Interestingly, the survey also revealed some negative results, showing that science museums are perhaps overly positive in their portrayal of science and scientists. For example, after the visit, visitors were more likely to think that “scientists always agree with each other, that scientific explanations are definite, and that science has the answers to all problems.”

\textsuperscript{59} Ibid., 723. Visitors indicated that the visit had increased their interest in science, made science less mysterious and more accessible, taught them something new, or broadened their perspectives.
Not only do science museums play important roles in building relationships with science, but they can also engage visitors in the scientific process—encouraging them to ask their own questions and to test proposed solutions and helping them develop the skills needed to evaluate scientific claims and to make decisions about scientific issues. Science museums can also introduce visitors to the fact that the scientific process is not a simple, linear process that will always lead to the correct conclusion, but rather that it is a complicated process and that scientific findings are often preliminary and changing as new discoveries are made.\(^{60}\) In discussing the value of understanding the process of research, Bruce Lewenstein and Rick Bonney of Cornell University, write,

…if a museum can help someone understand how research is conducted—that scientific investigation involves observations and trials, controls and correlations, repetitions and revisions—then that individual should be able to understand and evaluate scientific claims and conclusions encountered in the course of daily life.\(^{61}\)

In concert with many of the recent nationwide initiatives to improve scientific literacy in this county, many science museums have rededicated themselves to engaging visitors in the scientific process—and

\[^{60}\text{Rick Bonney, “Understanding the Process of Research,” in Creating Connections: Museums and the Public Understanding of Current Research, David Chittenden, Graham Farmelo, and Bruce V. Lewenstein, eds. (Walnut Creek, CA: AltaMira Press, 2004), 199.}\]

\[^{61}\text{Bruce V. Lewenstein and Rick Bonney, “Different Ways of Looking at Public Understanding of Research,” in Creating Connections: Museums and the Public Understanding of Current Research, David Chittenden, Graham Farmelo, and Bruce V. Lewenstein, eds. (Walnut Creek, CA: AltaMira Press, 2004), 65.}\]
laboratory exhibits are one new tool in this effort. Additional evaluation of the effectiveness of science museums at accomplishing this goal is needed, but specific efforts to engage visitors in the scientific process show some success. Science museums clearly have an important role in increasing public science literacy. They are most effective not in teaching specific science content but in inspiring and exciting visitors about science and in providing them with the skills they need to critically assess the world.

**Influential Educational Philosophies and Visitor Research**

As science museums have evolved from the object-oriented museums of science and industry to the phenomena-based participatory science centers of today, their exhibits have evolved and proliferated as well. There is now a dramatic range of types of exhibits. Even in 1986, when Victor Danilov wrote his history of science museums and science centers, he was able to identify ten different exhibit types. These included not only participatory exhibits but also “live demonstrations, simulated environments, working models, telephone narrations, animated objects, miniatures and enlargements, projected dioramas, videotape monitors,

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large-screen films, and many other techniques.” A 1999 article in Museum News, the American Association of Museums’ bimonthly publication, highlighted more recent developments in exhibit techniques, including environmental exhibitions that place visitors into replicated environments, immersion exhibitions that immerse visitors in a preprogrammed experience, visitor-responsive digital media, and much more.

Science museums have taken a lead role in evaluating their exhibits and programs to determine their educational impact. Although a few museums undertook evaluation efforts earlier, the real impetus for visitor research began with the passage of the Elementary and Secondary Education Act in 1968, which required that 5 to 10 percent of the budget of any federally-funded education program be spent on evaluation. Particularly since the 1980s, when the National Science Foundation began to require that funds be spent on evaluation, science museums have gained a great deal of knowledge about their visitors and the types of exhibits that produce the most evidence of learning.

A wide range of learning theories also influence today’s science museum exhibits. When educational learning theories and the results of

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63 Danilov, Science and Technology Centers, 195.
exhibit research are examined together, a picture emerges of the types of exhibits that are most likely to result in high levels of learning. Ideal museum exhibits are experience-based, are constructivist, appeal to multiple learning styles, provide opportunities for social interaction, are intrinsically motivating, and contain a wide range of design features that stimulate learning. As will be substantiated in my Findings and Conclusions, each of these learning concepts has significantly influenced the development of laboratory exhibits.

Educational theorist John Dewey’s experience-based learning theory has had a significant impact on the development of museum exhibits and programs. Dewey proposed that all learning was a result of direct experience and the learner’s reflection on that experience. But, he argued that “not all experiences are genuinely or equally educative.”

He believed that the most successful educational experiences were both immediately enjoyable and influential later on. He wrote,

> Perhaps the greatest of all pedagogical fallacies is the notion that a person learns only the particular thing he is studying at the time. Collateral learning in way of formation of enduring attitudes, of likes and dislikes, may be and often is much more important than the spelling lesson or lesson in geography or history that is learned. For these attitudes are fundamentally what counts in the future.

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The most important attitude that can be formed is that of desire to go on learning.\textsuperscript{67}

According to Dewey, an experience is the interaction between the internal actions taking place within an individual and their external environment at that time—including the educator, materials and equipment, and social situation. He felt that the environments that are conducive to learning provide “time, talk, and tools”—time to ask questions and investigate; opportunities to share ideas and ask questions with parents, teachers, and peers; and access to authentic tools such as scientific instruments.\textsuperscript{68} He also stressed that the most effective experiences present learners with a problem to be solved—a problem that the learners are both capable of solving and that inspires in the learner a desire to seek out additional information and knowledge.\textsuperscript{69}

Dewey saw museums as a fundamental part of formal education, but he emphasized that museum experiences should be connected to broader life experiences outside the museum. In describing the challenges that Dewey’s theories present to museums, educational theorist George Hein noted that museum experiences “require integrated settings that foster discussion, challenge the learner, make connections to issues of

\textsuperscript{67} Ibid., 49.
interest to the learner, and provide guidance for application in the world outside the museum.”\textsuperscript{70} Hein explains that it is this last challenge—applying their experiences to the outside world—that remains the most difficult for museums to achieve.

Science Museum Consultant Ted Ansbacher, a proponent of experience-based exhibits in museums, describes how Dewey’s theory of learning through experience can be seen in a common science museum exhibit called a gravity well. A gravity well consists of a funnel with sides that increase in steepness toward the bottom. Visitors can launch satellites (balls or coins) and observe the effect of gravity as the satellites move closer to the bottom. The balls orbit slowly at the top of the funnel, where the force of gravity is weaker, and speed up as they reach the bottom to counteract the stronger forces of gravity. Ansbacher describes this relatively simple interactive as follows:

The gravity well provides direct experience which is \textit{in itself} meaningful. It can be observed and explored, it can lead to inquiry and experimentation, and in engaging with it a visitor develops \textit{physical knowledge} of the “orbits” of balls rolling around a funnel—all without reading interpretive labels.\textsuperscript{71}


\textsuperscript{71} Ted Ansbacher, “The Rose Center for Earth and Space at the American Museum of Natural History: An Experience-Based Critique,” \textit{Exhibitionist} 21, no. 2 (Fall 2002): 30.
Taking root in the work of Dewey, constructivism—the concept that individuals construct their own knowledge internally by reflecting on their experience—is another influential learning theory that has specifically impacted museum exhibits. Developmental psychologist Jean Piaget also significantly influenced the theory of constructivism. Piaget found that people construct knowledge by accommodating or assimilating new knowledge to their prior knowledge. Prior knowledge is the building block of learning and can either confound learning or support it. Over time, people develop schemata—overarching views of the world. Most of the time, individuals assimilate new information into their existing schemata, reinforcing their view of the world. Less often, individuals come across information that cannot be assimilated into their existing schemata. This cognitive conflict forces individuals to enter into a process of accommodation, reinterpreting their schemata to better fit with the new information or experience. The creation of cognitive conflict is an important tool to help visitors construct more complete knowledge about the world.

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Piaget also studied cognitive development and found that children’s minds develop in a series of identifiable stages progressing from an understanding of concrete concepts to more abstract ones and from an ego-centric worldview to a more reflective one.\textsuperscript{74} Cognitive psychologist Jerome Bruner built on Piaget’s work to develop a series of recommendations about how science and mathematics should be taught based on a child’s developmental stage—progressing from concrete to abstract experiences. According to educational theorist David Kolb, the experience-based curriculum developed by Bruner meant that “children became ‘little scientists,’ exploring, experimenting, and drawing their own conclusions.”\textsuperscript{75} Piaget and Bruner’s work on developmental stages is being applied in museums, as Linda Black of the Children’s Museum of Indianapolis says, by providing “science learning environments [that] involve various senses and motor skills, present real objects and apparatus, and provide opportunities for hands-on exploration of concrete and abstract concepts.”\textsuperscript{76}

More recent research has shown that Piaget’s developmental stages are more flexible than previously thought—that not all children have the

\textsuperscript{75} Ibid., 14.
same abilities at the same ages and that a single person’s reasoning ability
may vary depending on the task. Recent research has also shown that
knowledge can help to develop a child’s reasoning ability and
understanding of scientific concepts. To help enhance logical thinking
and scientific understanding, psychologists Lauren Resnick and Michelene
Chi advocate for knowledge to be presented in an organized manner
(rather than the collection of interesting unrelated facts presented by many
science museum exhibitions). They also state that learners need time and
repeated exposure to a concept in order to fully understand it, that
laboratories that allow learners to expand on their knowledge can be very
valuable, and that discussion and appropriate tools play important roles as
well. Resnick and Chi propose,

Informal educators must invite learners to solve problems
and otherwise go beyond the material presented.
Knowledgeable persons must be available to help guide
novices as they elaborate. Informal educators need to invite
and support social interaction explicitly and not just to
permit it to happen passively.

Educator David Hawkins has also built on the constructivist theory
to develop his own theory of effective science teaching. According to
Hawkins, the best science education must have three phases—messing

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Lauren B. Resnick and Michelene T.H. Chi, “Cognitive Psychology and Science
Learning,” in A New Place for Learning Science: Starting and Running a Science Center,
Sheila Grinell, ed. (Washington, D.C.: Association of Science-Technology Centers,
1992), 81.
Messing about, according to Hawkins, is a phase where learners are “given materials and equipment—things—and are allowed to construct, test, probe, and experiment without superimposed questions or instructions.” Next, children should be guided through more structured activity but should still have a wide range of activities from which to choose—what Hawkins calls multiply programmed material. This variety of activity ensures that children of all abilities and learning styles have the opportunity to make connections between their discoveries in the messing about phase and the structured activities in the next phase. Finally, it is only after these two phases are complete that lecture can be introduced to explain concepts and ideas.

George Hein, author of *Learning in the Museum*, has developed a vision for the “constructivist museum,” which has three essential components. First, the museum must recognize and accommodate the fact that learners construct their own knowledge. Second, the museum must make the process of learning an active and engaging process. Lastly, the museum must make learning accessible to the visitor. In Hein’s view, a

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79 Ibid., 74.
constructivist museum gives visitors freedom, offers them a comfortable environment, allows them to feel competent, and gives them a sense of control. The constructivist museum connects its exhibits and programs to the visitors’ prior knowledge in order to allow them to have experiences that build on that knowledge, offers exhibits that accommodate multiple learning styles, and emphasizes social interaction.

Constructivist exhibits are open-ended with no prescribed path, accommodate a range of learning styles, show a range of points of view, offer a range of activities that are connected to a learner’s prior knowledge and past experiences, and allow visitors to experiment and come to their own conclusions.81 Several exhibits at the Boston Museum of Science provide excellent examples of constructivist exhibits. In many of these exhibits, the museum “provides equipment and materials to do a variety of investigations with some ideas on how to get started. From there, it’s up to the visitors to decide where to go.”82 One example of an exhibit in this model is a solar car exhibit, which is one component of Investigate! A See-for-Yourself Exhibit. Visitors can put together solar cars, changing the wheel size and adjusting the tension on a pulley that connects the car’s

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81 Ibid., 34-36.
axle and motor, and then test how fast their cars go on a race track. They can set challenges for themselves and test and retest until they meet them.

In her study of visitor behavior at Techniquest (United Kingdom) and Science North (Ontario, Canada), researcher Chantal Barriault found that constructivist exhibits, like the solar car exhibit described above, lead to deep learning. Barriault identified eight distinct learning behaviors that visitors display. She divided these into three categories—initiation behaviors (the first steps toward meaningful learning), transition behaviors (which show that the visitor is comfortable and eager to engage more deeply with the activity), and breakthrough behaviors (which reflect the visitor’s interest in and commitment to further exploration). Her findings indicate that experiences that are most conducive to breakthrough behaviors are constructivist exhibits, which, according to Barriault,

…provide relevant, contextualized exhibits which make reference to visitors’ everyday lives; provide tools and activities which encourage exploration, interactions and involvement; and provide exhibits which have numerous outcomes and testable variables.83

In addition to designing constructivist exhibits, science museums also seek to develop exhibits that appeal to multiple learning styles. Bernice McCarthy’s 4MAT learning cycle describes four distinct learning styles. Type One learners are people who learn from experience and

personal connection. These types of learners gain the most from having a direct experience and value authenticity. Type Two learners are people interested in concepts and ideas. Type Three learners are people who learn through hands-on activities, exploration, manipulation, testing theories, and applying concepts. And Type Four learners are those who make connections between what they are learning and the broader world. They crave opportunities to be creative and think imaginatively.\textsuperscript{84} The most effective learning experiences, according to McCarthy, are those that can appeal to all four learning styles. In her article “Learning Theory and Current Science,” Rita Mukherjee Hoffstadt described a hypothetical exhibit about the Earth that would appeal to all four learning styles. This hypothetical exhibit would immerse visitors in the sights, smells, and textures of the Earth (appealing to Type One learners), would present information on Earth science concepts (appealing to Type Two learners), would allow visitors to experiment with technology that lets them see how the Earth has changed over time (appealing to Type Three learners), and would ask thought-provoking “what-if” questions such as what it would

\textsuperscript{84} Bernice McCarthy, \textit{The 4MAT System: Teaching to Learning Styles with Right/Left Mode Techniques} (Barrington, IL: EXCEL, Inc., 1980).
mean if we found another planet similar to Earth (appealing to Type Four learners).  

Many science museum exhibits are also designed to encourage social interaction, building on Lev Semenovich Vygotsky’s socio-cultural theory of learning. Vygotsky explored the impact of the “zone of proximal development”—a theory that a child’s ability to learn can be extended through interaction with more knowledgeable others, either adults or more advanced children. More capable individuals are able to help less skilled individuals reach their potential through a process called scaffolding. In this process, the more skilled individual provides assistance or tools that help the other person advance through a step-by-step process that builds on what they already know and helps them reach a higher level of understanding. Many schools are adopting this theory by using cooperative learning, a technique that involves shared work and responsibility to help each other learn. Research has shown that children remember more of what they have learned when they explain it to

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86 Russell, “Experience-Based Learning Theories.”
someone else and that children’s learning reaches more advanced stages when they collaborate with others.\textsuperscript{88}

The Philadelphia-Camden Informal Science Education Collaborative (PISEC) has been conducting research on exhibit features that enhance social learning, particularly in family groups. PISEC identified seven exhibit characteristics that contribute to family learning: multi-sided exhibits that families can gather around, multi-user exhibits where more than one person can engage simultaneously, exhibits that are accessible to both children and adults, multi-outcome exhibits where visitors can discuss and compare their findings, multi-modal exhibits that appeal to a range of learning styles and abilities, readable exhibits, and relevant exhibits that are linked to visitors’ prior knowledge. In a 1997 study, PISEC developed four components that were added to existing exhibits to enhance the exhibits’ ability to contribute to family learning. These family learning components—each developed for a different museum—included an interactive graphic station featuring 10 pull-up cards with interesting facts about mole rats; a family activity kit including a fish anatomy puzzle, stamping and coloring activity, and short book about camouflage; a family activity kit featuring a fossil matching activity,

dichotomous key for fossil identification, and magnifying glass; and an experiment station where families can try out mini-pendulums. The addition of these components to existing exhibits resulted in substantial increases in learning behaviors (asking questions, answering questions, commenting on the exhibit, and reading the text silently or out-loud) and increased time spent at the exhibits.

Intrinsically motivating experiences also tend to be effective educational experiences. Psychologist Mihály Csikszentmihályi distinguished between two types of motivation—intrinsic and extrinsic. Intrinsic motivation describes the desire to participate in an experience for its own sake, in the absence of external rewards. Individuals who are intrinsically motivated often experience a “flow experience” where they become utterly engaged in the experience, losing their sense of time or place. Csikszentmihályi believes that museum experiences must provide internal motivation or “the visitors’ attention will not focus on it long enough for positive intellectual or emotional changes to occur.” He identified four characteristics that can contribute to producing a flow

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experience. First, the experience must have clearly stated goals and rules. Second, the experience must provide clear and immediate feedback. Third, the challenge of the experience must be well matched with the skills of the visitors. Finally, as the learners’ skills increase, the challenges must increase as well. Csikszentmihályi also distinguished between challenges that spell out the problem to be solved and those that let the visitor discover the problem, indicating that the latter is more likely to result in intrinsic motivation.92

Deborah Perry, Director of Selinda Research Associates, a Chicago-based museum evaluation firm, has also identified features of museum experiences that cause them to be intrinsically motivating. Building on research done on computer games, she came up with the following seven features: curiosity, confidence, challenge, control, play, and communication. She recommended that exhibits pique curiosity by asking questions. Museums can instill a sense of confidence in visitors by making sure their exhibits are intellectually accessible and creating ways for visitors to share their interpretation of the exhibit with others. Museums should also offer a range of challenges at a variety of skill levels, give visitors choices, offer opportunities for visitors to engage in

playful activities, and provide opportunities for social interaction. Perry singles out *The Color Connection: Mixing Colored Light* at the Museum of Science and Industry in Chicago, which allows visitors to experiment with colored light projections, as one exhibit designed using these criteria. Bright lights piqued visitors’ curiosity and the exhibit held their interest by posing a series of intriguing questions. The low reading level of the exhibit text promoted a sense of confidence and allowed visitors to explain things to one another, as did easy initial interactions. The exhibit challenged visitors through a choice of activities—making hand shadows or specific light colors—and gave them a sense of control by allowing them to manipulate the lights with switches. Several suggested activities, such as crawling through the lights, putting objects in the lights, and making up stories about the hand shadows, encouraged exploratory play. Finally, the exhibit encouraged social interaction through a computer guide that placed one visitor in the role of teacher and the other in the role of student.

Exhibits that tell stories can also be powerful tools for enhancing learning, as can exhibits that encourage imaginative play. A group of researchers from the University of British Columbia and the Queensland

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University of Technology in Australia has been examining factors in museum environments that contribute to children’s learning. Their research involved ninety-nine children that participated in a year-long, multi-museum, multi-visit study in Australia. Although the children’s museum memories and learning were extraordinarily diverse and idiosyncratic, there were several common features that tended to make certain exhibits more memorable. These included large-scale exhibits, tactile experiences, and experiences that were connected to familiar events in the children’s lives. Additionally, experiences told in a narrative or story format tended to be more memorable. For example, children tended to remember artwork that evoked stories, theater-based experiences, or exhibits that connected to their cultural history—such as exhibits about a local mine and local air force base. Children had much more difficulty recalling exhibits that were decontextualized or that were not connected to their prior experience. The study concluded,

> Museum experiences that provide context and links with children’s own culture—that is, their customs, beliefs, and values that they hold—will provide greater impact and meaning than exhibits and experiences that are decontextualized in nature. In particular, experiences that are embedded in the medium of story, play, and objects that can be readily identified by children, are powerful mediators.\(^{94}\)

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\(^{94}\) David Anderson et al, “Children’s Museum Experiences: Identifying Powerful Mediators of Learning,” *Curator* 45, no. 3 (July 2002).
Exhibits that engage visitors in imaginative play or role-playing can also be powerful learning experiences, particularly for younger visitors. For children, these kinds of experiences can provide an opportunity to rehearse for future roles, to experience a position of power, to make connections with other cultures, and to see themselves differently.⁹⁵

Additional recent research into exhibit effectiveness has identified several additional design features that are conducive to learning. Much of this research relies on two common measures used to evaluate an exhibit—attraction and holding power. Attraction refers to the number of visitors (as a percentage of all visitors) who stop at a particular exhibit for a minimum time period. Holding power refers to how long visitors spend engaging with a particular exhibit.⁹⁶ Several research studies have examined the factors that lead to increased attraction, holding power, and learning behaviors in an exhibition. Research into exhibit effectiveness in the 1970s and 1980s determined that attraction and holding power were increased by concrete (incorporating three dimensional objects) rather than abstract (text and pictures only) exhibits and by dynamic rather than static

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Early studies also showed that manipulative exhibits were more successful than their hands-off counterparts at attracting visitors and stimulating their curiosity and interest.98

Building on the results of these early studies, researchers Dorothy Lozowski Boisvert and Brenda Jochums Slez examined the effectiveness of exhibits at Boston’s Museum of Science in terms of attracting visitors, holding their attention, and engaging them. They characterized exhibits as concrete or abstract, high interaction or low interaction and simple or complex (depending on the difficulty of concepts presented). They found that concrete exhibits had the highest attraction levels, that high interaction and concrete exhibits had the greatest holding power, and that high interaction exhibits produced the highest levels of visitor engagement. Moreover, their research showed that staffed exhibits produced the highest levels of all three measures. An example of the type of exhibit that produced the highest level of visitor engagement was a demonstration station where a staff member dissected a pig’s heart.

Cody Sandifer of Townson University (Townson, MD) examined visitor use of sixty-one interactive exhibits at the Reuben Fleet Science

Center (San Diego, CA) and found two additional factors that contributed to increased holding time.\textsuperscript{99} The first characteristic was technological novelty, that is, exhibits that contain state-of-the-art technology or that use technology to enable a visitor to have an experience they could not otherwise have. Examples of technologically novel exhibits included one that uses a laser to produce sounds and an exhibit that records a visitor’s movement and plays it back in time reversal. The second factor was open-endedness, seen in exhibits that allow the visitor to interact in multiple ways or achieve multiple goals. An example of an open-ended exhibit is Pattern Blocks, which consists of geometric tiles that can be used to create an unlimited number of patterns.

The wide range of exhibit features outlined above can be tied together in the contextual model of learning developed by John Falk and Lynn Dierking of the Institute for Learning Innovation. Their learning model describes how three different contexts—personal, sociocultural, and physical—interact with each other over time to determine what and how visitors learn during a museum visit. The personal context is the visitor’s personal state of mind during their visit—their motivations, interests, emotions, and prior knowledge and experiences. The sociocultural context describes both the immediate social experience at the museum and the

\textsuperscript{99} Sandifer, “Technological Novelty and Open-Endedness,” 121-137.
broader cultural and historical context that impacts the visitor. Finally, the physical context is the actual physical setting of the museum.\textsuperscript{100}

Museums can be designed to emphasize various aspects of these contexts in order to create environments that are conducive to learning. For example, by providing engaging and personalized experiences, offering visitors a wide range of choices about the activities in which they may engage, and providing challenges that are appropriate to their skill level, museums can influence the personal context. By developing experiences that promote within-group interaction, between-group interaction, and visitor-staff interaction, learning can be increased. Finally, by orienting visitors to the space, creating physical environments that are moderately novel, locating conceptually similar exhibits near to one another, and using design elements that are conducive to learning behaviors, museums can also create physical spaces that increase the likelihood of learning taking place.\textsuperscript{101}

The characteristics of ideal exhibits described here—experience-based, constructivist, appealing to multiple learning styles, socially engaging, intrinsically motivating, and stimulating learning—have been used to design a wide range of exhibits, from table-top style interactives to computer-based exhibits to dioramas or immersive environments.

\textsuperscript{100} Falk and Dierking, \textit{Learning from Museums}.

\textsuperscript{101} Ibid.
Laboratory exhibits, as defined in this paper, are frequently designed with these exhibit philosophies in mind and are, as J. Newlin, Director of Physical Sciences and Technology at the Science Museum of Minnesota described them, about a process, not about a right answer. My Conclusions, presented later in this paper, will describe how well laboratory exhibits achieve each of these characteristics.

The Roots of Laboratory Exhibits

Laboratory exhibits grew out of two significant exhibit trends: the development of discovery rooms and the increased emphasis in many museums on developing exhibits about the process of science. Discovery room exhibits emerged in the early 1970s in parallel with the development of the modern science and technology centers. Originating in natural history museums, discovery rooms are staffed spaces where visitors can have hands-on access to real and reproduced specimens and can engage in free exploration. They are quiet spaces where visitors can engage in concentrated activities. A description by one set of evaluators, Judy Diamond, Anita Smith, and Alan Bond, of the discovery room at the

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103 In his article, “Messing About in Science,” educator David Hawkins describes the value of free exploration. By allowing visitors to become familiar with objects and begin to ask their own questions, free exploration can prepare visitors for a deeper level of inquiry.
California Academy of Sciences in San Francisco reveals one of the fundamental goals of discovery rooms: “by touching and investigating natural objects, visitors learn that interesting things can be discovered through their own explorations.”¹⁰⁴ Two of the earliest discovery rooms were the Touch and See Room at the L.F. Bell Museum of Natural History in Minneapolis and the Object Gallery at the Florida State Museum in Gainesville, FL. But, it was not until the Smithsonian National Museum of Natural History opened its discovery room in 1974 that these types of exhibits began to gain popularity.¹⁰⁵ This space featured large specimens and a variety of discovery boxes that contained smaller specimens, labels, and exploratory tools. The original goals of the space were both to allow visitors to have a hands-on experience with authentic objects and to study what this adds to the visitor experience. The museum sought a space that would attract frequent visitors and also wanted to provide a model for other museums around the nation.¹⁰⁶ Many museums did follow in the Smithsonian’s footsteps. By 1985, a survey revealed 100 different discovery spaces in museums around the world.¹⁰⁷

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Science museums soon followed the lead of the natural history museums. One of the first science centers to open a discovery room was Boston’s Museum of Science in 1978. Like the early discovery rooms in natural history museums, the first science center discovery rooms were targeted at young children. The discovery room at Boston’s Museum of Science provided opportunities for visitors to touch objects, use their senses, and develop observation skills—one of the fundamental steps in the scientific process.¹⁰⁸

Discovery rooms can provide powerful learning experiences for visitors. In observing the behaviors of sixty-two visitor groups to the Discovery Room at the California Academy of Sciences in 1988 (which drew a total of nearly fifteen thousand visitors over a three month period) researchers found that visitors spent an average of eighteen minutes in the room, touching objects (the most popular activity), and engaging in social interaction (which greatly enhanced the educational experience). Children spent nearly three times as long interacting with objects when they were interacting with another individual than when they were exploring on their own (1.4 minutes compared to 30 seconds) and were more likely to

explore more deeply, asking questions and making comments. Other research studies have revealed that people who use discovery rooms tend to be repeat visitors and that the dwell time in discovery rooms is typically higher than it is for other exhibits. There is also some evidence that visitors are learning more specific facts or content from their experiences in these spaces than they are from other exhibits.

Today, discovery spaces, similar to their precursors, still exist in relatively the same form in science museums across the county. However, these spaces also evolved as the museums evolved. Two of the significant changes were the creation of spaces that were designed for visitors of all ages rather than for the museum’s youngest visitors and the development of discovery spaces that were thematic or closely tied to larger exhibitions in the museum. For example, when the Liberty Science Center opened in New Jersey in 1993, it featured discovery rooms tied to each of its three major exhibit themes—invention, health and the environment. In many ways, discovery rooms are the predecessor of today’s laboratory exhibits,

111 Chuck Howarth, Former President, Liberty Science Center, interview by author, April 5, 2005, Oakland, CA.
which also seek to provide visitors with access to real objects and engage them in authentic experiences with science.

Laboratory exhibits were also influenced by the recent trend toward developing exhibitions that are specifically designed to teach the scientific process. One example of this type of exhibition is Inquiry, which opened at the Museum of Science and Industry in Chicago in 1985. The exhibition sections, entitled Exploring Our World, Observing, Finding Out, and Explaining, sought to increase visitors’ skills in these fundamental aspects of scientific thinking, with the overarching goal of increasing scientific literacy. Several Do An Experiment! stations in the Finding Out section allowed visitors to determine the shape and color of a hidden object by forming hypotheses and conducting experiments—rotating, manipulating, or shooting at the object with a pinball launcher. According to the summative evaluation, these experiment stations were among the most popular exhibits, a finding supported by the learning theories described above. The evaluation also revealed that, after exploring the exhibition, over 80 percent of visitors could at least partially explain the scientific process and over 25 percent of visitors felt that the
exhibit changed their view of scientists, helping them see that science could be interesting and fun.\textsuperscript{112}

More recently, growing concern about the state of scientific literacy in the United States and its potential economic impact—and the publication of several national reports emphasizing a change in the way science is taught—have inspired additional museums to attempt to develop exhibits that engage visitors in the scientific process. In 1989, Boston’s Museum of Science adopted a new long-range plan, entitled “Science Is An Activity.” This long-range plan was a significant shift from the museum’s previous smorgasbord approach of displaying interesting exhibits from a variety of scientific disciplines side-by-side.\textsuperscript{113} The museum was responding both to test results that showed American students falling behind international students in their ability to apply scientific thinking skills and to the 1989 Science for All Americans report published by the American Association for the Advancement of Science. Under this plan, the museum has been developing its exhibits to meet several of the goals laid out in the AAAS report—encouraging individuals to ask questions, think critically, and actively participate in the process of science. According to a museum press release, exhibits give “visitors


practice in observing and experimenting, and in a number of other scientific thinking skills as well.” To date, the Boston Museum of Science has developed three new permanent exhibitions under this plan. The first, *The Observatory: A Place for Seeing the Unseen*, focuses on developing observation skills—providing exhibits that encourage visitors to use all of their senses to make observations, to test the limits of their perception, and to use technology such as microscopes and infrared cameras to see the world in a new way. The second exhibition, *Investigate! A See-For-Yourself Exhibit*, described earlier in this paper, includes activities such as designing and racing a solar car, experimenting with materials to see if Styrofoam retains heat better than other materials, and analyzing findings from a simulated archaeological dig. The museum’s third exhibit in this vein, *Science in the Park*, looks primarily at the physics of motion but with the same eye toward utilizing scientific thinking skills. With these new exhibits, the museum sought to move away from the idea of science as a set of facts and sought to present it as a process which must be actively pursued and practiced. Through this

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114 Boston Museum of Science, “A New Kind of Exhibit.”
117 Boston Museum of Science, “Science is An Activity.”
practice, visitors can come to understand the scientific process and learn to critically evaluate information presented to them.

The Boston Museum of Science is just one museum that has developed exhibits to engage visitors in the scientific process with the goal of strengthening scientific thinking skills. In his 1997 article in *Technology Review*, Larry Bell, Vice President for Exhibits at Boston’s Museum of Science, described efforts by various science museums to develop exhibits that “resemble working laboratories, where visitors can pursue their own short research projects and find their own answers to the questions they themselves pose.” At museums including Science North in Sudbury, Ontario, the Science Museum of Minnesota, the Oregon Museum of Science and Industry, and the Fort Worth Museum of Science and History, exhibits are engaging visitors in the scientific process. The earliest laboratory exhibits were developed in parallel with these exhibits and had many similar goals.

In conclusion, evidence of the educational benefits of laboratory exhibits is compelling. These exhibits can help to meet not only a curricular need but also societal needs by helping the public understand the scientific process and develop positive feelings about science. And, they are supported by a wide-range of learning theories and exhibit

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research that documents the effectiveness of authentic experiences, constructivist learning, social engagement, and intrinsic motivation, as well as specific design features that contribute to learning. But questions remain about how effective these types of experiences are at teaching the scientific process as well as what the best ways are to implement these exhibits in order to achieve their goals of increasing scientific literacy. The following section presents an analysis of my research into the various museums that have developed or are planning to develop a laboratory exhibit, their goals and objectives, and the effectiveness of these exhibits at teaching the scientific process.
FINDINGS & CONCLUSIONS

We owe it to people to give them a personal experience around a subject area that helps them see themselves within that discipline and understand they have the potential to contribute. This is the essence of what museums should be doing.

– Peggy Monahan, Former Director of Exhibits and Programs, The Tech Museum of Innovation

What do we really know about how effective laboratory exhibits are and how can we improve them? Through a literature review, a nationwide survey, interviews, and site visits, I have developed a series of suggestions for how to develop these exhibits to promote scientific literacy and how to evaluate these experiences to ensure that they are meeting this goal. My findings examine the current scope of these exhibits and the justification and reasoning behind their development. Next, I discuss a range of laboratory exhibit formats, particularly focusing on wet labs, labs embedded in the context of a story, labs designed for frequent change, and open-ended exploration labs. Each format description includes two or three examples of existing laboratory exhibits that utilize that particular approach. These examples reveal both the significant educational impact that these exhibits can have on visitors and the issues—in terms of both visitor engagement and, to a limited extent, practical logistics—that

exhibit developers must consider in order for that impact to occur. I also
examine the limitations of existing evaluation of these exhibits and discuss
the necessary steps to evaluate these exhibits. Finally, I explore the many
significant factors that are preventing more museums from developing
laboratory exhibits and discuss some of the creative ways that museums
have overcome these difficulties.

Laboratory exhibits can be powerful tools for engaging visitors in
the process of science, enabling them to see themselves as scientists and
helping them to feel capable and competent to use their own scientific
thinking skills to answer questions or solve problems. Rooted in
experience and providing opportunities for visitors to construct their own
understandings of how the world works, these exhibits are also supported
by a wide range of learning theories. Successfully developing these
exhibits, however, requires an understanding of the successes and failures
of those who have tried before. This understanding will help inform the
next generation of these exhibits, as museum professionals continue to
seek out the best ways of providing individuals with authentic experiences
with the scientific process.
Scope of and Impetus for Laboratory Exhibits

The development of laboratory exhibits is a recent trend, growing in part out of increasing concern about the state of scientific literacy in the United States. To gain an understanding of the breadth of institutions developing these exhibits, I sent a survey to 145 exhibit directors at science museums across the country. The seventy surveys returned reveal robust interest in the development of these exhibits. Nineteen of the respondents (27 percent) indicated that they already have a laboratory exhibit in their museum. An additional nine museums (13 percent) indicated that a laboratory exhibit is included in their future plans. These museums range dramatically in size, from the small Impression 5 Science Center in Lansing, Michigan, to the Science Museum of Minnesota, one of the largest and most prestigious science museums in the country. They also cover a wide range of geographic locations, from California to New York and from Minnesota to Texas. Most of the exhibits (sixteen) have opened since 1995, revealing the emergence of this trend over the last decade.

Survey respondents cited a wide range of reasons for developing laboratory exhibits. Foremost among them is the idea of engaging visitors in the scientific process. In the survey results, fifteen museums (79 percent of those with laboratory exhibits) identified “teaching the scientific
process” as one of the reasons they developed the exhibit. More museums selected this response than any other.

Follow up interviews with museum exhibit staff also revealed the importance of engaging visitors in the scientific process as an impetus for developing these exhibits. In describing the *What Made the Kids Sick?* laboratory exhibit at Exploration Place in Wichita, Kansas, former museum president Al DeSena stated that one of the goals was to develop process-oriented thinking skills rather than to just transmit information.\(^{120}\) The museum sought to engage visitors in a process of problem-solving—of sorting through information and using observation and scientific tools to solve a problem. DeSena said, “We talk so much about the importance of helping the public understand the processes of science. These kinds of experiences at least make an effort.”\(^{121}\) Interviewees also stated that one common goal of these exhibits is to help visitors change their picture of what it means to be a scientist and envision themselves in this role.

Research indicates that many of our nation’s youth continue to hold stereotypical views of scientists. A 1997 nationwide study used the Draw-A-Scientist-Test, where children create a visual depiction of a scientist, to evaluate students’ views of scientists and science. The study found that

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\(^{120}\) Al DeSena, Former President, Exploration Place, telephone interview by author, April 20, 2005.

\(^{121}\) Ibid.
most children still see scientists as white males in laboratory settings, and older children are more likely than younger children to associate stereotypical characteristics with scientists (lab coats, eyeglasses, etc.).

Charlie Walter, Chief Operating Officer at the Fort Worth Museum of Science and History, stressed that the science lab in the *Lone Star Dinosaurs* exhibition is about empowering visitors to realize that anyone can be a scientist: “We want people to get a sense that everybody has a curiosity about the natural world and can make deductions….They can read something in the paper and explore it further.”

Underlying the goals of engaging visitors in problem solving and using scientific thinking skills is the larger goal of helping visitors learn how to learn. Andy Aichele, Senior Director for Exhibition and Volunteer Programs at the Center for Science and Industry (COSI) in Columbus, Ohio, emphasized that while learning goals and outcomes are important, the idea of learning how to learn was key to his museum’s Gadget’s Cafe:

Content has been emphasized for so long; we are trying to prove that people learn things. Maybe we have been focusing too much on whether visitors know the boiling temperature of liquid nitrogen rather than that they want to learn more. Spending more time on developing good habits

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of learning is going to be a bigger payoff in the end than having them walk out and say “that was cool.”

Other reasons for developing laboratory exhibits identified in the survey included teaching specific science content (selected by eleven museums) and strong interest by an individual board or staff member (selected by five museums). A smaller number of respondents identified reasons such as providing experiences in a laboratory setting, allowing visitors to role-play as scientists, and offering family learning experiences. Martin Weiss, Director of Science at the New York Hall of Science, said one of the key goals of his museum’s laboratory exhibit was to provide a place where children can work in concert with their parents and engage in intergenerational learning.

**Laboratory Exhibit Formats**

According to survey results, existing laboratory exhibits focus on a wide range of scientific disciplines, with the most popular topics being biology (thirteen museums), chemistry (ten museums), physics (ten

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124 Andy Aichele, Senior Director for Exhibition and Volunteer Programs, Center of Science and Industry, telephone interview by author, April 18, 2005.
125 Survey respondents were able to select multiple reasons for offering a laboratory exhibit.
museums), and paleontology (seven museums).\textsuperscript{127} There are also a wide range of types of experiences offered in these spaces, including access to real scientific tools (seventeen museums); opportunities to interact with staff, volunteers, or scientists (sixteen museums); structured step-by-step challenges (thirteen museums); and opportunities for open-ended exploration (twelve museums).\textsuperscript{128} The majority of the exhibits (fourteen) are staffed at least part-time with volunteers or paid staff. Depending on the exhibit, staff either engage actively with the visitors—facilitating their inquiry process—or work primarily behind the scenes, setting out supplies, cleaning up, and assisting as necessary.

These types of exhibits can take a variety of forms. Four potential laboratory exhibit formats include wet labs, labs embedded in the context of a story, labs designed for frequent change, and open-ended exploration labs. Although all these formats have commonalities, they are also distinct in many ways.

\textit{Wet Labs}

Wet labs, or traditional laboratory set-ups where visitors can participate in wet science experiments, are one format that museums are

\textsuperscript{127} Numbers do not equal the total number of museums because museums may have more than one laboratory exhibit or exhibits may focus on more than one scientific discipline. \textsuperscript{128} Again, many laboratory exhibits offer multiple types of experiences.
using to engage visitors in the scientific process. These experiences can, in many ways, be considered prototypical laboratory experiences, most clearly fitting the definition outlined in this paper. When the Oregon Museum of Science and Industry opened its chemistry lab in its new building in 1994, it was one of the first museums in the country to offer the public the chance to engage in wet chemistry experiments. Since then, several other museums have begun to offer these types of experiences, including the Science Museum of Minnesota (SMM), the Tech Museum of Innovation (San Jose, CA), and the New York Hall of Science.

Visitors to the Science Museum of Minnesota’s Cell Lab immediately sense that the experience they are about to enter is singular. The 1,000-square-foot space is surrounded by a low wall, allowing visitors to see into the space but providing a barrier that signals to them that this is an unusual experience. Upon entering through the gate, visitors put on the proper scientific attire—a lab coat, goggles, and gloves. “Once they’re in, they’ve made a commitment. They’ve invested in getting all dressed up,” described J. Newlin, Director of Physical Sciences and Technology at SMM. Within the lab space, visitors can select from six different activity stations (called Lab Benches) with a range of complexity and required preparation.

time commitment. Activities include preparing and examining their own cheek cells under a microscope, extracting DNA from raw wheat germ, testing the effectiveness of antibacterial agents, identifying bacteria using staining and chemical tests, analyzing how well their saliva can digest starch, and extracting DNA from a fruit fly. Visitors are led through each activity by a Lab Companion—a multimedia computer assistant, which provides step-by-step instructions while still allowing the visitors to work at their own pace, even going back as necessary. The Lab Companion has a youthful voice, which provides a feeling of peer-to-peer guidance rather than top-down direction.

In an exhibit modeled on SMM’s Cell Lab, the Tech Museum of Innovation’s Wet Lab allows visitors to insert real jellyfish genes into bacteria. As the bacteria grow, they produce glowing jellyfish protein. Centrally located in the middle of the Tech’s Genetics: Technology with a Twist exhibition yet set off by a barrier, the lab has room for four small groups to complete the experiment simultaneously. Similar to the Cell Lab, visitors are led through the exhibit at their own pace using a computer-based guide. Unlike the Cell Lab experience, however, where the results are visible immediately, visitors to the Tech’s Wet Lab must wait until the next day to see their glowing jellyfish protein. The Tech handles this complication using a system of Radio Frequency
Identification (RFID) tags. Before beginning their experiment, visitors register their tag on an RFID reader. The next day, to view their results, they log onto the Tech’s website using the code from their tag and see the glowing bacteria they created. Through a partnership with Stanford University, the Tech has a full-time staff scientist and several graduate student interns working at the museum. The scientist, Dr. Barry Starr, played an essential role in developing the Wet Lab activity and helped the museum find ways to reduce the cost of the activity and shorten the time needed to complete it.130

At the New York Hall of Science, a less-technical approach allows visitors to try out thirteen different simple biology and chemistry experiments. In the 1,100-square-foot Pfizer Foundation Biochemistry Discovery Lab, up to thirty-six visitors can engage in a wide range of experiments that are tied to everyday life—answering questions such as “How do antacids work?,” “What molecules make the holes in bread?,” or “How do bees talk to each other?” Most of the experiments use readily available household materials, and a series of simple pictographic labels, rather than computer guides, lead visitors step-by-step through their experiments. These simple labels do not require a high literacy level,

meaning that they are less likely to intimidate visitors.\textsuperscript{131} In a 2001 article in ASTC Dimensions, Martin Weiss, Director of Science at the Hall of Science, described the Biochemistry Discovery Lab as conveying “a broader message about the process of science. As visitors actively use controls, try experiment replication, and employ careful observation, they discover more about how scientists explore the world.”\textsuperscript{132}

Each of the three wet lab exhibits described above was developed as a complementary component of a larger exhibition. SMM’s Cell Lab links to the Human Body Gallery, the Wet Lab at the Tech is part of a new exhibition on genetics, and the Biochemistry Lab at the New York Hall of Science is part of the Marvelous Molecules: The Secret of Life exhibition. Eric Yuan, an exhibit developer at the Tech, described the reason for offering this as a complementary component of an exhibition: “In the Genetics exhibit, we simulate a lot of things…. At the Web Lab, you get to do science yourself. It’s as close as you can get to feeling like you are a scientist.”\textsuperscript{133} Martin Weiss, Director of Science at the New York Hall of Science, indicated that the lab’s presence within a larger exhibition was one of the successes of the space. “Visitors can see the activities from the

\textsuperscript{131} Martin Weiss, interview by author.
\textsuperscript{133} Eric Yuan, interview by author.
exhibition and become attracted to what is going on…They look in and see people doing things and say, ‘I want to do that.’”

These exhibits have pushed the envelope in terms of the expected level of time commitment and concentration required for an exhibit—requiring ten or more minutes to complete an individual activity. At the Tech, for example, the staff uses a general rule that visitors must be able to understand the idea of an exhibit in three seconds, read the directions in thirty seconds, and complete the activity in three minutes. With these guidelines, introducing exhibits that take a minimum of ten to twenty minutes to get the initial payoff can be a real risk for a museum. Yet, in each of these three cases, the risk paid off—revealing that visitors are willing to invest additional time when they are fully engaged. All three experiences engage visitors for a much longer period of time than other exhibits in the museums. Timing and tracking studies conducted at the New York Hall of Science revealed that visitors spend an average of twenty-six minutes in the laboratory. When compared to a national study showing that visitors spend an average of 11.5 minutes in an exhibition in general, these findings become very significant. The time spent on a single activity averaged 7.4 minutes, five times longer than the average of

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134 Martin Weiss, interview by author.
135 Eric Yuan, interview by author.
1.5 minutes per exhibit for the related Marvelous Molecules exhibition.

Most Biochemistry Discovery Lab visitors (75 percent) engaged in more than one activity in the lab, and a few groups participated in more than ten experiments. At the Tech Museum, summative evaluation of the Genetics: Technology with a Twist exhibition found that the median amount of time spent in the Wet Lab was ten minutes while the median time spent in the whole Genetics exhibition was only seven minutes. The Wet Lab was also the third most visited exhibit, with 31.4 percent of visitors engaging with it. The Science Museum of Minnesota reported similar findings.

Evaluation showed that visitors spent a median of fourteen minutes at a single Lab Bench, compared to a median of one minute at nearby cell-related exhibits. While time spent engaging with an exhibit is certainly not a definitive measure of the educational benefit of an experience, it can be indicative of learning, engagement, and interest.

Formal evaluations of these experiences also show that visitors seem to be engaged, enjoy the experience, and come away with an understanding of the basic concepts behind the exhibit. At SMM’s Cell Lab, many interviewed visitors indicated that they found the Lab Benches to be more interactive and interesting than other exhibits at the museum.


Observation of visitor behavior showed that visitors were actively engaged in the exhibits, with a majority doing activities (54 percent), talking about exhibit content (54 percent), looking at specimens (52 percent), reading exhibit text (52 percent), or watching others do activities (50 percent). Overall, visitors were also able to understand and identify the core messages of the exhibit—that science is approachable and how cells function—or took away specific ideas or concepts from particular experiments.\textsuperscript{139}

In the evaluation of the Tech Museum’s \textit{Genetics} exhibition, one-third of visitors indicated that the Wet Lab was their favorite experience. The majority of Wet Lab participants were able to explain what they had done in the experiment, indicating that their experience was deeper than simply following a series of steps. Most were able to make a connection between what they were doing and genetic medicine, the main content goal of the exhibition. Evaluators also found that none of the visitors were misusing the exhibit.\textsuperscript{140}

The New York Hall of Science reported similar findings. Here, 44 percent of interviewed visitors understood that the activities were connected around the topic of molecules or chemical reactions, 56 percent


\textsuperscript{140} Randi Korn & Associates, \textit{Genetics Summative Evaluation}. 
were able to correctly explain something they learned about molecules, and 69 percent were able to identify and describe chemical reactions that took place. Visitors also thought the activities were more fun (65 percent) and more interesting (68 percent) than activities in other parts of the museum, and 56 percent of visitors indicated that they learned more from the lab activities than other museum exhibits. Most visitors followed the exhibits through, completing all of the steps to perform an experiment.\textsuperscript{141}

While neither the New York Hall of Science nor the Tech Museum explicitly stated engaging visitors in the scientific process as one of the goals of the exhibit, all three exhibits showed success in some areas of this goal—such as providing visitors with experience with real scientific tools or helping them see themselves as capable of engaging in science. The Science Museum of Minnesota’s Cell Lab exhibit goes even further with at least one exhibit that takes visitors through the steps of the scientific process—from hypothesis formation to reaching their own conclusion.

All three of the exhibits were successful in making visitors feel empowered—at least momentarily—about their ability to do science. Interview quotes from all three evaluations emphasized that visitors appreciated doing real science, feeling like real scientists, doing experiments on their own without help, and testing ideas for themselves.

\textsuperscript{141} New York Hall of Science, \textit{Biochemistry Lab Summative Evaluation}.
The sense of independence and control seemed important to many visitors. One ten year old girl at the New York Hall of Science stated, “At school I do experiments on the teacher’s orders—here I do it myself.”

The Science Museum of Minnesota and The Tech Museum’s exhibits are also effective at providing visitors with access to real scientific tools. Both museums made conscious decisions to use real equipment and materials even though simpler and less expensive alternatives might have been available. At The Tech, for example, exhibit developers decided to use pipettes rather than eye droppers because they are integral to real laboratories. At the Science Museum of Minnesota, visitors use real microscopes rather than the easy-view Wentzscopes (with a single lens and large focus control) common in many museums. The museum staff wanted visitors to have experience with real scientific tools. However, the microscopes have been modified slightly to make them easier to use. Other real tools used in the experiments at SMM include stains and chemicals, test tubes, slides, and incubators.

The Science Museum of Minnesota has one activity that is especially notable in that it takes visitors through the steps of the scientific

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142 Ibid., 25.
143 Eric Yuan, interview by author.
144 J. Newlin, interview by author.
process from hypothesis formation to conclusion—rather than just a portion of this process. The Testing Antimicrobials station allows visitors to test how effective common antimicrobial agents are at killing bacteria. Visitors first have the choice of selecting three different agents to test. They may select from bleach, Ivory soap, antibacterial soap, antibacterial hand gel, or household liquid cleanser. They are then asked, based on their life experience, to make a hypothesis about how effective each agent will be in killing bacteria and record their hypothesis into the computer. After conducting an experiment, they examine each sample under an ultraviolet light, compare it to a control sample, and interpret their own results. This exhibit engages visitors in making a hypothesis based on observation and prior knowledge, conducting an experiment, and reaching their own conclusions. In this way, this activity provides visitors with a greater understanding of how science works. According to formative evaluation, the exhibit is particularly effective in engaging visitors in social learning—discussing ways to improve the procedures, debating which solutions to test or predictions to make, and interpreting the results together. The exhibit also provides a clear, understandable introduction to some techniques that scientists use, such as the use of controls in experiments.\footnote{Randi Korn \& Associates, Inc., \textit{The Science Museum of Minnesota: Select Cell}} This particular exhibit also provides an excellent example
of how these types of exhibits can result in cognitive dissonance—a strong learning tool for constructing knowledge. Many visitors are surprised by the results of the experiment, and this causes them to rethink their choice of antimicrobial agents in their own lives.

Another SMM Lab Bench provides an opportunity to show the complexity of science, although perhaps not intentionally. The Giant Chromosomes Lab Bench, where visitors extract chromosomes from a fruit fly, has a relatively low success rate, with less than half of visitors successfully extracting the chromosomes. The formative evaluation shows that visitors enjoy the experience, even when they are not successful, and recommends that the museums use this activity as a tool for teaching visitors something about the process of science. The evaluation states,

Visitors can learn a valuable lesson from not being able to create a chromosome slide—that science is difficult, requires not only knowledge of content, but also mechanical skill, is time consuming, and often does not end in success… Visitors value authentic science experiences and will likely be responsive to learning more about the scientific process.

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147 Science Museum of Minnesota, _Cell Lab Cookbook_, 112.

These three exhibits also provide models for how these experiences can build on visitors’ prior knowledge, engage family groups, and provide intrinsically motivating experiences. The New York Hall of Science’s Biochemistry Discovery Lab made a specific effort to connect with visitors by tying exhibits to concepts with which they are familiar. Martin Weiss, Director of Science at the Hall of Science, explained that the museum sought to “pick topics that are going to engage people and relate to them and to the world that they know.”\(^{149}\) Activities focus on chemical reactions that visitors see evidence of every day—making cheese using bacterial action, investigating the pigment in flowers and leaves, or exploring what molecules cause the ocean to foam. In the museum’s summative evaluation, 85 percent of visitors interviewed about the exhibit said that there was something familiar in the activities or that the activities related to their daily life.\(^{150}\) SMM’s Cell Lab provides an example of another way to relate these exhibits to visitors’ lives—by having visitors examine something about their own bodies. Visitors can look at their own cheek cells under a microscope or test how well their saliva digests starch. The science of the human body is a powerful hook for engaging visitors. Sylvia Branzei, the author of five “grossology” books examining the science of bodily functions (the concept has also been developed into a

\(^{149}\) Martin Weiss, interview by author.

\(^{150}\) New York Hall of Science, *Biochemistry Lab Summative Evaluation.*
blockbuster museum exhibit), explained that “when you’re teaching children, if you’ve thought of something or started teaching them about something that was a little bizarre or a little gross, they were more and more interested in it.”

All three museums discussed here designed their wet labs specifically to engage family groups. Each wet lab has room for groups of two to six to work together. At the Science Museum of Minnesota, several of the activities enable visitors to each conduct their own experiment in a parallel process. Recent research at the Exploratorium in San Francisco has shown that multiple station exhibits (exhibits where there are multiple places to control the experience) result in a much greater engagement level and can hold the interest of whole family groups at the same time, particularly in cases where visitors could otherwise interfere with each other when exploring the exhibit’s phenomenon. Additionally, formative evaluation at SMM found that the multimedia computer program that guides visitors through the steps in the experiment can free the adults to participate in the activity with their child rather than reading label copy or serving as a guide.

In addition to promoting family learning, all three laboratory exhibits also provide opportunities for visitors to interact with museum staff and volunteers. Each of the three spaces is staffed during its open hours with an employee who can answer questions, replenish supplies, and deal with any problems. Evaluations at the Science Museum of Minnesota show that this interaction has been beneficial for both the staff members and the visitors. At SMM, the Cell Lab is staffed by a combination of paid staff, volunteers, and a youth Lab Crew of high school students. SMM’s J. Newlin explained that the museum decided to use youth staff in the lab in part to attract more young people to science through peer-to-peer interaction. Evaluation has shown that visitors appreciate having the staff present to assist them and that the presence of the youth staff makes the experience more comfortable for children and teens. Similarly, the staff and volunteers also appreciate the opportunity to work with the public. Most youth staff indicated that this was their favorite part of their job. The design of these laboratory spaces encourages social interaction—both within group and between visitors and museum staff—which is key to learning.

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154 J. Newlin, interview by author.
These exhibits also provide examples of how exhibits can promote intrinsic motivation. According to psychologist Mihály Csikszentmihályi, four characteristics contribute to creating intrinsically motivating experiences: clearly stated goals and rules, clear and immediate feedback, a challenge that is well matched with the skills of the visitors, and challenges that increase with the learner’s skills. In the three wet labs described here, the structured step-by-step instructions provide clear goals and rules. The Science Museum of Minnesota and the New York Hall of Science selected activities that could provide results in a short period of time. While the results of the experiment in the Tech Museum’s Wet Lab cannot be seen until the next day, the Tech allows visitors to get an immediate response by looking at a previous visitor’s results. As the Tech’s Eric Yuan stated, “To get visitors to stay ten minutes, they need to really feel that they’re doing something; they need visible results.” This concept is similar to Csikszentmihályi’s concept of clear and immediate feedback. The Science Museum of Minnesota effectively handles Csikszentmihályi’s ideas of multiple and increasing levels of challenge by offering six activities that range in difficulty and complexity. Staff members talk to visitors to recommend the right exhibit for their skill level, and visitors can progress to more difficult activities.

157 Csikszentmihályi and Hermanson, “Intrinsic Motivation in Museums,” 70.
158 Eric Yuan, interview by author.
evaluation of the most complex activity—extracting fruit fly chromosomes—showed that visitors were appropriately challenged by the complexity of the exhibit and were perhaps more diligent here than at other activities. The evaluation states, “teens and children, in particular, enjoyed the independence and the feeling of being adults doing serious work. Adults, too, saw the bench as ‘real science’ and valued the chance to learn something new.”\(^\text{159}\) Visitors were engaged and did not mind spending a significant amount of time at this activity.

Wet lab exhibits have the potential to significantly impact visitors’ learning, but they also have limitations in their learning potential. Foremost among these are the reduced numbers of visitors reached and the lack of opportunity for open-ended exploration or independent experimentation. Wet lab exhibits reach fewer numbers of visitors than traditional interactive exhibits. In the summative evaluation for the Science Museum of Minnesota, evaluators observed visitors interacting with both Lab Benches and related cell exhibits. Over the evaluation period, far fewer visitors engaged with the Benches than the traditional exhibits (sixteen compared to fifty).\(^\text{160}\) There are two primary factors that influence the number of visitors served. First, because visitors engage with the laboratory exhibits for a longer period of time, the exhibits may be in-


use more often than other exhibits. The second reason is because of the
visitors themselves. Not all visitors want to spend ten to thirty minutes at a
single exhibit when they are trying to explore the whole museum in a
limited time period. As a result, these exhibits may be likely to attract a
particular type of visitor. Interviewees indicated that these types of
experiences work best for frequent museum users or visitors with a
particular learning agenda, such as school groups. As SMM’s J. Newlin
said, “First time visitors want to see everything. When they come back,
they have a sense of the whole place.”

This is the time, Newlin says,
when visitors are likely to use these exhibits. According to Johanna Jones,
Senior Associate at Randi Korn & Associates, who conducted the
evaluation for both SMM’s Cell Lab and the Tech Museum’s Wet Lab,
these exhibits “encourage repeat visitors and are [designed] for repeat
visitors.”

The second major limitation to this exhibit style is the lack of
opportunity for open-ended exploration. There is little opportunity in these
exhibits to conduct experiments that the visitors themselves, rather than
the museum, design. The Hall of Science’s Martin Weiss described the
problem as follows:

161 J. Newlin, interview by author.
162 Johanna Jones, Senior Associate, Randi Korn & Associates, interview by author, San
Francisco, CA, April 11, 2005.
The challenge remains developing activities that are sufficiently open-ended and allowing visitors to go on to explore other questions…. They get to the end and raise questions, but there is no way to give them the opportunity to explore the questions. You need to have materials and supplies to go ahead and do something like that. That was the major challenge and still remains the major challenge for any activity of a biological and chemical nature.\textsuperscript{163}

There are several reasons why this is so difficult. First, visitors may come to the exhibit with little previous experience with laboratories or experimentation. Leaving visitors to design and conduct their own experiments without guidance would likely have little value. As Randi Korn & Associate’s Johanna Jones said, “If you don’t know how to do an experiment, you have to have someone model it for you.”\textsuperscript{164} The Tech Museum’s Eric Yuan agreed, saying, “to direct your own involvement, you have to come to the exhibit with an understanding of the tools.”\textsuperscript{165}

Once visitors have conducted a guided experiment and gained familiarity with the tools and materials, there is the potential for them to continue the exploration on their own, asking their own questions or expanding on the experiments. However, as SMM’s workbook on the Cell Lab exhibit cautions, “there are limits to how far you can go in an informal environment. Reagents and supplies can be costly and bench maintenance can become extensive if you let visitors ‘just mess

\textsuperscript{163} Martin Weiss, interview by author.
\textsuperscript{164} Johanna Jones, interview by author.
\textsuperscript{165} Eric Yuan, interview by author.
Additionally, evaluation and experience shows that, even when presented with the opportunity, visitors are unlikely to continue their exploration at the same activity. One SMM Lab Bench, Enzymes in Saliva, was designed to provide visitors with opportunities to continue their exploration after the initial experiment. After analyzing how well enzymes in their saliva can digest starch, visitors have the opportunity to engage in additional experiments, testing how quickly the enzymes work, how long they continue to work, and the impact of stomach acids on the enzymes. Yet, evaluation found that few visitors wanted to continue their exploration after the initial procedure, preferring instead to go on to other Lab Benches. Perhaps the significant length of time required for each activity discourages visitors from continuing their exploration.

Similarly, the activities at the New York Hall of Science attempt to engage visitors in designing experiments for further exploration. Instructions at the end of activities ask visitors if they have their own questions and encourage them to experiment to find out the answers. However, evaluation showed that few visitors stayed to continue the experimentation. The evaluation states that “it was often observed that children wanted to stay and ‘play’ but the adults with them appear to need

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167 Ibid., 101.
more structure to justify staying longer.”168 Rather than encouraging additional exploration on-site, the Tech provides activities on its website for further exploration. Evaluation is needed to determine how many visitors use these activities, however. Additional research might result in the development of other ways to encourage visitors to continue their experimentation and ask their own questions. SMM’s J. Newlin states that these exhibits continue to develop “in incremental steps; we’re waiting for people to come and do the next version.”169

Labs Embedded in the Context of a Story

Narrative can be a powerful tool to increase learning, and several museums have developed laboratory exhibits using a story as a guiding theme. Rather than setting up a series of loosely connected experiments—a technique used in the wet lab exhibits—the experiments are connected in a story format, often set up as a mystery which visitors must solve. An examination of labs at Exploration Place in Wichita, Kansas, and the Fort Worth Museum of Science and History reveals some of the strengths and weaknesses of this approach.

169 J. Newlin, interview by author.
The *What Made the Kids Sick?* exhibit at Exploration Place sends visitors on a quest to determine the cause of a food poisoning incident. As visitors enter the exhibit, they receive an introduction to the story—several children have become sick after a school picnic—and are introduced to some audiovisual characters who tell their story. Moving into the laboratory itself, visitors conduct a series of lab experiments designed to help them solve the mystery—looking at food samples under a microscope, taking the pH of several items, and engaging with interactive computer stations. After completing the experiments, visitors reach their own conclusions about what made the kids sick and can post their answer in a section of the exhibit.

At the Fort Worth Museum of Science and History, another story-based lab exhibit focuses on strengthening visitors’ observation skills. In the *Lone Star Dinosaurs* exhibition, visitors begin by entering a recreated dinosaur quarry site, rich with fossils. The museum has set up several devices—staff members, videos, and interpretive guides—to attempt to get visitors to use their observation skills to study the dinosaur bones, associated fossils, and rock sediments. Next, visitors enter a science lab area where they can use scientific instruments to explore further. Here, visitors measure dinosaur bones and use scientific formulas to determine how big the animals were, look at the animals’ teeth to determine what
they ate, look through microscopes to make comparisons, and more. When they have completed their experimentation, visitors can enter their findings into a computer—painting a picture of what life was like in North Texas 100 million years ago.

One of the strengths of this format is the use of narrative to engage visitors. According to Charlie Walter, Chief Operating Officer at the Fort Worth Museum, “you have to have a compelling story. You have to get visitors in the door and get them motivated.”

According to Walter, a story that engages visitors can be much less intimidating than walking into a laboratory setting with Bunsen burners and test tubes—an environment that has little connection to many visitors’ lives. Former Exploration Place president Al DeSena agreed that the use of story can create an experience that is personally relevant to visitors. According to DeSena, this is more effective than basing exhibits on abstract concepts or unfamiliar scientific research: “Telling stories, I believe, is important in many of the things we do in the museum world. It is a major way of helping visitors relate to content and activities.”

Both exhibits seek to strengthen visitors’ scientific thinking skills. Al DeSena emphasized that for visitors who take the time to use the What

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171 Charlie Walter, telephone interview by author.
172 Al DeSena, telephone interview by author.
173 Ibid.
The exhibit as it is intended, the exhibit can accomplish this goal. He described the exhibit as adding coherence to the visit, incorporating both science content and science process. According to DeSena, visitors can reach a deeper level of learning in these types of exhibits than in traditional interactives.\(^{174}\) Similarly, according to the Fort Worth Museum’s Charlie Walter, the goal of the *Lone Star Dinosaurs* exhibit was to help visitors understand that “science is not just content; science is a way of thinking. Our philosophy is that if we can empower visitors to know that they can be scientific thinkers, they can build a deeper understanding of all kinds of science.”\(^{175}\) Front end-evaluation at the Fort Worth Museum of Science and History revealed that few visitors knew how to look closely at specimens and most visitors were not confident in their scientific research skills. Most visitors said that if they had to identify a specimen, they would turn to external resources (books, the internet, scientists, or educators) rather than using their own observation skills.\(^{176}\) But, the evaluation also showed that visitors were able to make detailed observations and inferences once they were guided through the process. Based on these findings, the museum sought to

\(^{174}\) Ibid.

\(^{175}\) Charlie Walter, telephone interview by author.

develop tools to empower visitors to use their observation skills. Tools include staff guides, videos of people role-modeling this process, and interpretive labels. The structure of the exhibition—having visitors collect clues to piece together a picture of the past—was also designed to motivate visitors to use their scientific thinking skills. The exhibition opened in May 2005 and summative evaluation has not yet been conducted. Once it is complete, it will reveal the effectiveness of these methods in empowering visitors to think scientifically.

While the use of story is a powerful tool, this exhibit format can be complex to develop and design. These types of experiences tend to be larger exhibition components that do not necessarily have the same intimacy and staffing level of a wet lab experience. As a result, there is more reliance on interpretive materials—signage and audiovisual components—to provide a comprehensive picture of what the exhibit is about and how the components relate to one another. For some visitors, this is sufficient to engage them in solving a mystery. Others may not grasp this idea and, therefore, may not get the most out of the exhibit. Because of the limited staff, the tasks within the exhibit need to be simple enough that individuals with limited experience using scientific tools can...
still feel comfortable.\textsuperscript{177} This means that the level of complexity of the experiments or activities is much lower than can be accomplished in a wet lab—and it becomes even more difficult to engage visitors in designing their own experiments rather than replicating those designed by the museum. Exploration Place’s Al DeSena indicated that these exhibits work best when they are facilitated by a staff person who can orient visitors to the concept of the exhibit and the tools available.\textsuperscript{178}

These types of exhibits are problematic both to design and maintain. It can be difficult to design the exhibit in a way that it is clear to visitors how to proceed in order to solve the mystery, particularly when striving to maintain a non-linear structure—which research has shown to be more effective than linear arrangements at encouraging visitors to look more closely at exhibit elements and at communicating exhibit themes.\textsuperscript{179} Maintenance of these exhibits can be potentially costly as well. Because the exhibit consists of a series of interrelated experiences, the malfunction of one component can affect the entire experience. The whole area must be maintained as a unified experience.

Similar to the wet lab experience, this exhibit format is not conducive to reaching a large audience. Because these experiences are

\textsuperscript{177} Al DeSena, telephone interview by author.
\textsuperscript{178} Ibid.
time consuming, the visitors who do use these exhibits tend to self-select and are audience members who have a strong learning agenda, according to DeSena. He said museums must develop marketing that introduces the public to the idea that there are longer, more in-depth experiences available at the museum.

Labs Designed to Change

Several museums offering laboratory exhibits have made it a priority to offer experiences that change on an ongoing basis. The Oregon Museum of Science and Industry (OMSI) in Portland and The Science Place in Dallas, Texas, designed their labs with this goal in mind. These experiences work particularly well for frequent museum visitors, but developing easily changeable activities that are open-ended and allow visitors to pursue answers to their own questions remains a challenge.

The Oregon Museum of Science and Industry has effectively incorporated the laboratory exhibit experience into its overall structure. The museum has seven distinct laboratory spaces—focusing on chemistry, physics, holography, paleontology, life science, watersheds, and technology. When the museum opened its new building in 1992, it built on a prototype of a chemistry lab program in its old facility but decided to

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180 Al DeSena, telephone interview by author.
expand the idea to offer laboratory experiences for each content area covered by the museum. The goal was to provide visitors with in-depth experiences, opportunities to interact with messier and more fragile objects, and the opportunity to engage in more complex activities. Two of the laboratories—the Chemistry Lab and the recently redesigned Vernier Technology Lab—provide rapidly changing content, with activities that change on a weekly basis. In the Chemistry Lab, for example, weekly themes include food chemistry, household chemistry, industrial chemistry, and environmental chemistry, among others. In the Technology Lab, visitors explore computer and robot technology, biomedical technology, communications technology, household technology, and security technology.

At the Science Place, the 400-square-foot Inquiry Zone exhibit offers changing activities on a monthly basis. Much of the curriculum was developed by Dallas public school teachers working at the science center during a summer fellowship. New activities are also developed to fit with traveling exhibits or to match the interests of sponsors. In February, engineering activities are sponsored by IBM, while the American Chemical Society sponsors chemistry activities in October. Activities that take place in the space include make-it take-it activities, experiments with

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science equipment, demonstrations, and guided inquiry activities with staff leading visitors through a process of observing, hypothesizing, and testing.

In the technology-based wet labs or fully-developed story-based exhibitions, it can be costly and time-consuming to rotate activities out. But the laboratory exhibits at OMSI and the Science Place are designed with this in mind. At OMSI, the labs are equipped with extensive storage, modular tables, and easily changeable sign holders. Activities make use of simple, inexpensive materials, each of which fits in its own container which can easily be brought out or put away. This flexibility allows the labs to meet the needs of frequent visitors. According to Jan Dabrowski, former Science Director at OMSI, the museum designed its Chemistry Lab with the understanding that public schools would use the lab to teach chemistry in a way that the schools couldn’t do on their own.\(^ {182}\) Providing changing activities helped to meet their needs.

Engaging visitors in the scientific process is a goal of these spaces, and guided inquiry activities are the primary method employed to accomplish this engagement. Paul Vinson, Vice President for Programs, IMAX and Exhibits at The Science Place, described the type of inquiry-based interactions that take place in the Inquiry Zone. Here, visitors might be presented with a fish tank containing dry ice at the bottom. A staff

\(^ {182}\) Jan Dabrowski, Former Science Director, Oregon Museum of Science and Industry, telephone interview by author, April 20, 2005.
member asks a visitor to blow bubbles into the fish tank. When the bubbles remain suspended mid-tank, the staff person encourages the visitor to hypothesize about what might be going on, and then to take the next step and conduct an experiment—blowing bubbles outside the fish tank, scooping up the gas from within the tank and examining it, smelling it, and pouring it onto a lit candle. The goal, Vinson says, is to “get people to be able to observe and articulate what they are observing, and predict and make guesses of what might happen.”

Staff members are key to engaging visitors in the scientific process. As Vinson said,

> Getting people to come up with their own questions depends on the facilitator’s skill…. You need a facilitator who is used to asking questions, not giving answers, who can prompt their questioning, prompt their observation.

These spaces also promote social interaction. Similar to the wet lab exhibits, this social interaction benefits both the visitors and the staff. At OMSI, Jan Dabrowski found that the laboratory spaces have been very attractive to parent-child groups who have the opportunity to play together and engage in cooperative learning. The Science Place’s Paul Vinson indicated that customer satisfaction with the Inquiry Zone has been very high and that staff and volunteers are more engaged and active in this

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183 Paul Vinson, Vice President, Programs-IMAX-Exhibits, The Science Place, telephone interview by author, April 13, 2005.
184 Ibid.
185 Jan Dabrowski, telephone interview by author.
space than in the museum’s other exhibit areas.\textsuperscript{186} However, given the strong reliance on staff involvement in these spaces, training in inquiry-based learning techniques is essential. Because museum floor staff members tend to be students or young people just entering their careers, there is a lot of turnover in these positions.\textsuperscript{187} Museums must be willing to invest in training these shorter-term staff in how to engage visitors in order to make these exhibits most effective.

\textit{Open-Ended Exploration Labs}

The final laboratory exhibit format featured in this project is open-ended exploration labs. These are exhibits where visitors are given more freedom to ask their own questions and explore on their own. Of all the laboratory exhibit formats described in this paper, open-ended exploration labs have been the most successful at empowering visitors to formulate and design their own experiments. While structured challenges may be provided as a starting point, these are spaces where the visitors’ questions are more important than the answers. Two examples of this exhibit style are the Science Museum of Minnesota’s Experiment Benches and the Center for Science and Industry’s (Columbus, Ohio) Gadgets Café.

Though very different from one another in design and set-up, these two

\textsuperscript{186} Paul Vinson, telephone interview by author.
\textsuperscript{187} Ibid.
exhibits both seek to give visitors opportunities for truly open-ended
exploration.

The Science Museum of Minnesota’s ten Experiment Benches, which opened between 1991 and 1993, are some of the earliest examples of this exhibit style and are also more similar in design to traditional interactive exhibits than any of the other experiences described in this paper. In developing these exhibits, J. Newlin gave a great deal of thought to types of exhibit experiences.\textsuperscript{188} He identified four levels of interaction that can take place in an exhibit. A contemplative exhibit provides interaction on a mental level. A push-button exhibit allows the visitor to initiate the demonstration of a principle or phenomena. A pre-determined outcome exhibit has the visitor play a more participatory role, perhaps manipulating a single variable, but the outcome is set. The fourth level—experimental exhibits—include several variables and engage visitors in solving problems, ideally of their own choosing and through experiments of their own design. SMM’s goal was to design its Experiment Benches as experimental exhibits. These ten exhibits, located in semi-enclosed spaces, are designed for groups of visitors to work together. Here, visitors can experiment with pendulums, construct mobiles, make circuits, and more.

\textsuperscript{188} J. Newlin, interview by author.
The goal was for visitors to engage in an experimental process consisting of playing and observing, developing a question, forming a hypothesis, designing an experiment, testing their ideas, and drawing conclusions. Participating in this process is valuable, according to the museum, because “visitors gain a deeper understanding of the power and place of science in nature through engagement in the scientific process than through learning the accumulated results of science alone.”189 The museum acknowledged, however, that the process the visitors go through would not be nearly as formal as that described here.190 Some museum visitors may not even proceed past the stage of free exploration. However, as outlined in the Background section of this paper, the idea of free exploration or free play is an essential first step in the scientific process. In his article, “Messing About in Science,” David Hawkins argued that scientific phenomena are often unfamiliar to learners and they need a period to begin to explore and understand on their own. As he stated, “the need for sheer acquaintance with the variety of things and phenomena is more obvious, before one can embark on any of the roads toward the big generalizations or the big open questions of biology.”191

189 Sauber, Experiment Bench Workbook, 6.
190 Ibid., 5.
SMM’s exhibit development team sought to provide visitors to each experiment bench with an “early assured success.” By trying to get visitors to begin with a simple, easily repeatable experiment, the developers hoped to build the self-confidence of visitors and inspire them to try more difficult challenges, including eventually designing their own experiments.\textsuperscript{192} SMM’s Experiment Benches include “experiment cards” which provide easy, moderate, and challenging task for the visitors to attempt to accomplish. This allows visitors to feel successful early on in their exploration and to increase their level of challenge as they gain new skills. As outlined above, this is key to creating intrinsically motivating experiences. Yet, the goal is for visitors to quickly move beyond the experiment cards to begin to design and conduct their own experiments on questions of their choosing. As SMM’s J. Newlin said,

\begin{quote}
We provide the equipment, but the visitors ask questions and experiment to find the answer. It’s not about learning from experts; it’s about doing your own reasoning. Visitors can set up experiments that none of us have thought of and be successful.\textsuperscript{193}
\end{quote}

At COSI in Columbus, Ohio, a very different laboratory set-up also engages visitors in open-ended exploring and asking their own questions. At the museum’s 2,500-square-foot Gadgets Café, visitors must first make a “reservation” with the “Maitre D.” Returning at their reserved time,

\textsuperscript{192} Sauber, \textit{Experiment Bench Workbook}, 7.  
\textsuperscript{193} J. Newlin, interview by author.
visitors are allowed to select the option to “take apart” or to engage in “guided experiments.” Visitors who choose to “take apart” select a computer or other electronic device and are provided with tools to deconstruct it. Those who engage in guided experiments are provided with the parts they need to complete simple experiments, such as creating an Alka-Seltzer rocket or building a hot air balloon. Because the guided experiments are similar to experiences in wet labs or labs designed to change, this section focuses on the open-ended exploration that occurs in the “take apart” activities.

These exhibits are constructivist, with right answers not often provided to visitors. As J. Newlin said, “every answer is a nail on the coffin; it shuts off inquiry, shuts off thinking. If you tell people the answer, interaction time goes down. If you don’t, people want to know.”194 These types of experiences also give visitors extensive control, which has been shown to increase learning. As a result, these exhibits can provide very rich learning experiences for visitors. Summative evaluation of SMM’s Experiment Benches, for example, showed that visitors spend more time at these than at traditional exhibits. Additionally, visitors who used these exhibits were more likely to develop hypotheses and design experiments than visitors to more traditional exhibits. Their social

194 Ibid.
interactions were more meaningful and “a few visitors in particular appeared to experience rich and meaningful learning experiences.”

Chris Burda, Senior Exhibit Developer at SMM, described the powerful experience that can take place in these exhibits:

> The best experience is when you know you have time and you’re not sure what is going to happen. You feel calm enough to appreciate something new. Visitors feel something very personal. They really do learn something. It’s a revelation.

Although COSI has not conducted formal evaluation of the Gadgets Café, informal evaluation shows that the exhibit is very popular with visitors—among the top three rated exhibits at the museum. Andy Aichele, Senior Director for Exhibition and Volunteer Programs, indicated that the exhibit encourages cooperative learning and a sense of accomplishment. He added that visitors love the opportunity to tinker without fear of breaking something. The exhibit is particularly popular with girls, who may not be encouraged to tinker and explore in this way elsewhere in their lives.

While these experiences can provide deep and meaningful learning and are perhaps the most effective format for truly engaging visitors in the scientific process, they can also be challenging to visitors. SMM’s

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195 Perry, *Experiment Bench Summative Evaluation.*
196 Chris Burda, interview by author.
197 Andy Aichele, telephone interview by author.
summative evaluation revealed that feelings of frustration or intimidation were more common at the Experiment Benches than at other exhibits. Visitors were frustrated at not knowing what to do, not being able to successfully accomplish a task, or not having their questions answered. Additionally, although designed for groups, the Experiment Benches at SMM actually showed less instances of social interaction than traditional interactives. The social interaction that did occur, however, was shown to be more meaningful. The evaluator indicated that this surprising finding might have been the result of feelings of unfamiliarity or intimidation with the exhibit style, the content, or the tools. As with the other laboratory exhibits, there appears to be a need to educate visitors about what to expect at these types of exhibits. As J. Newlin asked, “How do you set people up to understand that it’s not about a right answer, it’s about a process?”

At COSI’s Gadgets Café, Andy Aichele indicated that getting visitors to engage in an investigative process on their own can be problematic. “I see visitors jump to investigate, but they haven’t made any observations or inferences. We have to slow them down.” As with the other laboratory exhibits, Aichele said this type of experience works best

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198 Perry, Experiment Bench Summative Evaluation, 21.
199 Ibid., 16.
200 J. Newlin, interview by author.
201 Andy Aichele, telephone interview by author.
when staff members are available to facilitate this process for visitors who need it. “The activity works best when I’m fully staffed and the café is half full,” he said. “Parents learn more and kids learn more.” Aichele’s staff is trained to assess a group’s interest and how much facilitation they require, to help them engage in a process of observation, to help elicit their own questions, and to provide them with the tools for finding the answer.

**Need for Evaluation and Emerging Evaluation Models**

The evaluation that has been conducted on these exhibits has been invaluable in determining their educational impact and has revealed much about how successfully these exhibits engage visitors in the scientific process. But, overall, little formal evaluation has been done. Of the nineteen survey respondents who indicated that they have a laboratory exhibit, only five (26 percent) have conducted a formal evaluation. And, despite the fact that fifteen out of nineteen museums (79 percent) indicated that one of their goals for the exhibit was to teach the scientific process, only two of the evaluations actually looked at the effectiveness of their exhibits at accomplishing this. According to Randi Korn & Associates’ Johanna Jones, museums must be explicit about their goals in order for

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202 Ibid.
evaluators to evaluate their impact.\textsuperscript{203} If a museum does not clearly state engaging visitors in the scientific process as a goal, an evaluator will not look for evidence of it.

It is also essential that exhibit developers clearly define what they mean by engaging visitors in the scientific process and describe it in terms of measurable visitor outcomes or behavioral objectives.\textsuperscript{204} In the summative evaluation for SMM’s Experiment Benches, for example, the evaluators had a clear definition of “experimenting behavior.” Evaluators looked for evidence of “playing with the apparatus, hypothesis making, designing and setting up experiments, observing results, making comparisons, and forming conclusions”\textsuperscript{205} and could compare the incidences of this behavior at the Experiment Benches to other exhibits. A study of the “Wizard’s Lab,” an early physics-based laboratory exhibit at the Lawrence Hall of Science (Berkeley, CA) also offers a set of behavioral objectives that can be utilized in other evaluations. Examined behaviors included working by trail and error, following instructions, working creatively (in ways that go beyond the instructions), following the example of others, working alone, working in a group, properly handling the equipment, making correct observations, understanding the meaning of

\textsuperscript{203} Johanna Jones, interview by author.
\textsuperscript{204} Ibid.
\textsuperscript{205} Perry, \textit{Experiment Bench Summative Evaluation}, 16.
an experiment, trying to understand more, and enjoying themselves.\textsuperscript{206} However, not each of these activities has equal weight in revealing visitor engagement in the scientific process. Scott Randol, a research associate at the Lawrence Hall of Science and a Ph.D. candidate in math and science education, has been developing several tools for assessing inquiry in science centers.\textsuperscript{207} Similar to the evaluations described here, he has identified fifteen skills that reveal that inquiry is taking place. However, he has also rated each of these skills or behaviors based on the level of engagement that they reveal. For example, manipulating the exhibit would be evidence of low-level inquiry, while backing up a claim with evidence would show high-level inquiry taking place. Randol’s assessment tools—which are not exhibit specific and can be used across a broad range of exhibits—can be useful tools for evaluating laboratory exhibits. The concept of “thick description”—or an understanding of cultural codes that help to distinguish the meaning of similar looking behaviors—can also be useful in evaluating whether true inquiry is taking place.\textsuperscript{208}

In addition to looking at behavioral outcomes, recent exhibit research at the Exploratorium is examining the types of questions that

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\item \textsuperscript{206} Matti Erätuuli and Cary Sneider, “The Experiences of Visitors in a Physics Discovery Room,” Science Education 74, no. 4 (1990): 486.
\item \textsuperscript{207} Scott Randol, Research Associate, Lawrence Hall of Science, interview by author, Berkeley, CA, June 3, 2005.
\item \textsuperscript{208} Clifford Geertz, The Interpretation of Cultures (New York: Basic Books: 1973), 3-30.
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visitors ask at different exhibits—questions about making things happen, questions about understanding the exhibit, orientation questions, perceptual questions, and off-task questions—as well as how they go about answering those questions. A similar approach could be applied to laboratory exhibits to determine if visitors are engaging in the scientific process.

Exploratorium Senior Researcher Joshua Gutwill emphasized the need for holistic evaluation, looking at visitors’ physical, intellectual, and social engagement to determine if these exhibits are engaging visitors in the scientific process. Physical engagement examines what the visitor is doing at the exhibit. Intellectual engagement looks at what the visitors are talking about—whether they are making predictions or forming hypotheses, whether they are making connections to the outside world, whether they have a self-conscious understanding that they are doing science, etc. Social engagement looks at within-group and between-group interactions that take place at the exhibit.

In developing evaluation tools, it is important to acknowledge that the type of inquiry that takes place within a science center may be on a very personal level and some of the higher level inquiry skills may not be utilized in this environment. The Lawrence Hall of Science’s Scott

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209 Joshua Gutwill, interview by author.
210 Ibid.
Randol, for example, states that in a fun, social environment, visitors are less likely to use scientific argumentation.211 Similarly, it may not be necessary to support claims verbally with evidence as all members of the group have witnessed the same exhibit outcomes. Science Museum Consultant Ted Ansbacher added that the inquiry that takes place in a science center tends to be very personal inquiry—based on a visitor’s own curiosities and interests. He said, “Inquiry is done at a very personal level; you can’t start with learning the science of the experts.”212 Developing appropriate evaluation tools and acknowledging the level of inquiry that visitors can reach are both key to performing meaningful evaluation that reveals the impact of these exhibits. More extensive evaluation will aid in the development of effective laboratory exhibits in the future.

**Preventive Factors**

My survey results show significant interest in the science museum field in developing these types of exhibits. Of the fifty-one respondents who do not already have a laboratory exhibit, thirty-four (67 percent) indicated that they would be interested in creating one. Of the remaining responses, thirteen said they were not interested, two said maybe, and two

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211 Scott Randol, interview by author.
did not answer the question. The factors preventing those interested from
developing these exhibits and the reasons given for why museums are not
interested in developing these exhibits were very similar, and I report them
together here. The three major factors preventing museums from
developing these exhibits are lack of staff (listed by 23 museums), cost
(listed by 22 museums), and space constraints (listed by 20 museums).
These concerns are faced even by the museums described more fully in
this paper. At the New York Hall of Science, for example, the end of grant
funding and financial difficulties meant that the wet lab hours had to be
reduced. After operating for one year with the lab open during all museum
hours, the public hours were reduced to weekends and two weekday
afternoons.\textsuperscript{213}

Several of the museums discussed in this paper have found creative
ways to overcome the real challenges outlined here. Finding alternative
and affordable staffing options can not only make these experiences more
inexpensive but can also provide a beneficial educational experience to the
staff. Some of the laboratory exhibits outlined in the paper have been
staffed by homeschooled students, work-study students at local colleges
and universities, and other youth staff. As outlined above, working in a
laboratory exhibit has been shown to be a significantly positive experience

\textsuperscript{213} Martin Weiss, interview by author.
for youth staff. Additionally, many museums have found that these types of exhibits make more effective use of staff than more traditional exhibits. As COSI’s Andy Aichele said,

You can have a well-trained, well-seasoned person in an exhibit gallery, and they can get in a zone or habit where they are just exhibit guarding or staring off into space. But you can’t be in an activity this intensive and just zone out.²¹⁴

Aichele said that as COSI has gone through staff layoffs in recent years, the museum has changed its focus from having a staff member in each exhibit hall and has moved toward using staff for more active experiences. Despite a reduction in staff numbers, guest satisfaction has actually increased.

Some museums have also found ways to cover costs through donated materials and sponsorships. At COSI, for example, a company called Tech Disposal collects old computers and electronics from local businesses, removes the data, and donates them to the museum.²¹⁵ This has reduced the materials budget for the Gadgets Café from around $6,000 to approximately $2,500 annually. Securing sponsorship is a key way to reduce the budgetary impact of these exhibits, and this works particularly well with laboratory exhibits that are designed to change. The Science Place in Dallas has been successful in securing sponsors, such as IBM, the

²¹⁴ Andy Aichele, telephone interview by author.
²¹⁵ Ibid.
American Chemical Society, and the National Olfactory Foundation, for monthly laboratory themes.\textsuperscript{216} The flexible design of this lab allows for easy change to meet a potential sponsor’s interest.

Most of the laboratory exhibits described here take up a large space and there are certain benefits to this, particularly in regard to signifying to visitors that this experience is different from what they might find elsewhere and may take more time. But, these types of experiences do not need to be in large areas. SMM’s Experiment Bench exhibits are fairly similar in size to traditional exhibits, and the Science Place’s Paul Vinson said he is looking for ways to incorporate some of the Inquiry Zone activities elsewhere in the building in much smaller spaces.\textsuperscript{217}

Conclusions

A significant number of science museums across the nation have already developed or are planning to develop laboratory exhibits in the near future. While teaching the scientific process was the most frequently listed reason given for the development of these exhibits, other justifications ranged from teaching specific scientific content to engaging families in social learning experiences. These exhibits have been successfully executed across a broad range of scientific disciplines and in

\textsuperscript{216} Paul Vinson, telephone interview by author.
\textsuperscript{217} Ibid.
a variety of different ways in order to achieve specific goals. Conclusions highlighted below focus on the value of these exhibits as learning tools, the challenges that these exhibits present to both museum professionals and visitors, and the factors that contribute to their success.

Laboratory exhibits can provide powerful learning experiences for science museum visitors by actively engaging visitors for extended periods of time, providing an enjoyable experience, effectively teaching scientific concepts, and engaging visitors in the scientific process. Additionally, they are clearly aligned with a wide range of learning theories. John Dewey’s experience-based learning theory is one of the fundamental ideas behind the development of laboratory exhibits. As much as they present scientific concepts, these experiences also engage visitors in a positive experience with the scientific process—providing visitors with an experience which will positively influence their future interactions with science. These are experiences that provide “time, talk and tools.” They are extended experiences that involve interaction with staff and real scientific instruments. And they are experiences that inspire visitors to explore and inquire. Finally, these experiences also often connect to science in everyday life—connecting the museum experience to the broader world.

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218 Russell, “Experience-Based Learning Theories.”
These exhibits are also designed in accord with the constructivist model, engaging visitors in experiences that enable them to construct more complete knowledge of the world. Many laboratory exhibits meet George Hein’s vision of a constructivist museum. These exhibits are frequently located in enclosed or semi-enclosed spaces, which, as Hein states, “are recognizable to visitors as settings for relaxed, engaged activity which can take time and in which the viewer would feel safe.”

Spaces accommodate groups of visitors, rather than individuals. Activities not only show how science connects to the visitor’s life, but also ensure that visitors feel challenged yet competent and successful. Perhaps most importantly, the purpose of these exhibits is not to provide visitors with a right answer but to engage them in a process by which they can construct their own knowledge about the world.

Another strength of laboratory exhibits is that they can reach and reward individuals with a variety of learning styles. They provide visitors with an authentic experience in a social setting, apply concepts to these experiences, engage visitors in a process of exploration and testing theories, and finally, link to the broader world by connecting to science in everyday life. Some formats are more effective at reaching certain types of learners than others. Open-ended exploration labs, for example, encourage

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visitors to ask their own questions and design experiments to find the
answers. These exhibits are particularly effective at reaching learners who
seek opportunities for self discovery and want to apply what they have
learned to the broader world.\textsuperscript{220}

Laboratory exhibits encourage social interaction—both within a
given group and between visitors and staff. This type of interaction creates
a “zone of proximal development,” which enables learners to learn more
deeply through their interactions with others than they would be able to
accomplish on their own.\textsuperscript{221} In several instances, these exhibits have also
been used as an opportunity to provide apprenticeship learning, as youth
and adult staff work together in the exhibit space.

Additionally, as outlined above, these exhibits include features
which make them likely to be intrinsically motivating. Many invite
visitors to conduct a specific experiment or seek to solve a specific
problem, providing clear goals and rules. These exhibits often include
experiments that provide an immediate visible response and accommodate
a range of skill levels. More open-ended laboratory experiences can also
produce flow experiences as visitors define their own problems to explore.

According to psychologist Mihály Csikszentmihályi, intrinsic motivation

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\textsuperscript{220} McCarthy, \textit{The 4MAT System}, 10. \\
\textsuperscript{221} Russell, “Experience-Based Learning Theories.”
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and flow experiences cause “positive intellectual and emotional change to occur.”

Design features that contribute to increased learning can and have been incorporated into many laboratory exhibits. Laboratory exhibits tend to be staffed spaces, include three dimensional objects, and are highly interactive. They can be characterized by both technological novelty and open-endedness. One of their distinguishing features is the use of real scientific equipment, which is technologically novel to most lay people. Many also offer visitors opportunities for open-ended exploration. Finally, these exhibits provide opportunities for free exploration and imaginative play—one of the key ways in which young children in particular learn about themselves and the world around them.

These exhibits have also been shown to be useful tools for engaging visitors in the scientific process. All are successful at engaging visitors in some aspects of the scientific process and a few have found ways to take visitors through the full process from forming a hypothesis to formulating their own experiments to reaching a conclusion. These semi-facilitated experiences model the process of experimentation for visitors. At the same time, they provide enough independence and control to empower visitors to see themselves—at least momentarily—as scientists

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222 Csikszentmihályi and Hermanson, “Intrinsic Motivation in Museums,” 69.
223 Lavilla-Havelin, “Role-Playing in Children’s Museums.”
and to self-consciously recognize that they are doing science. In her article, “Supermarket Science? Consumers and ‘The Public Understanding of Science,’” Sharon Macdonald describes how exhibits that incorporate choices, familiar experiences, and opportunities to engage as active participants can be empowering to visitors. However, the content of the exhibition remains controlled, to a large degree, by the museum, limiting the empowerment that can actually occur. Thus, further evaluation is needed to more fully determine the impact of these exhibits.

While these exhibits do show many signs of success, the development of these exhibits is not a simple process. In addition to practical issues of staffing, funding, maintenance, and space allocation, it also takes significant effort to make these successful learning experiences for visitors. One of the challenges to creating a successful learning experience is that laboratory exhibits tend to reach reduced numbers of visitors compared to more traditional exhibits. This is due both to the nature of the exhibits themselves, which tend to have a longer dwell time and reduced throughput, and to reduced interest by visitors who may not want to commit the time for these more intensive experiences. As a result, these exhibits tend to attract particular types of visitors, ranging from

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frequent museum visitors who do not feel obligated to explore the whole museum in one visit to visitors who are coming to the museum with specific learning goals. While these exhibits do reach smaller numbers of visitors, they provide a depth of experience that is not provided in traditional exhibits. As Anders Liljeholm, Lead Educator in OMSI’s Technology Lab, explained, “you trade off numbers for depth of experience.” OMSI views its offerings as an inverted pyramid, with traditional exhibits on top, laboratories in the middle, and programs at the bottom. With each level of the pyramid, smaller numbers of visitors are reached, but more in-depth experiences are provided.

It is also difficult with laboratory exhibits to provide open-ended experiences to visitors or to truly allow visitors to design their own experiments. While some of the exhibit formats described here, such as the open-ended exploration labs, can successfully accomplish this, many others have failed to do so. Again, the reason is twofold. First, providing ways for visitors with limited background knowledge or experience with experimentation to conduct meaningful experiments without guidance is not easy. Second, several efforts to get visitors to continue their exploration beyond the initial guided experience have proven unsuccessful as visitors either want to move on to the next exhibit or feel they need

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225 Anders Liljeholm, telephone interview by author.
more structure. Interviewees emphasized the need to identify open-ended exploration as a priority early on in the planning process and to study visitors to determine the inquiry process in which they engage in order to find ways to encourage continued exploration.

Laboratory exhibits can also be frustrating for visitors. Science Museum Consultant Ted Ansbacher describes how science museum visitors, unlike visitors to other types of cultural organizations, often come with expectations that they will learn something. Ansbacher said, “science center visitors don’t see scientific phenomena as akin to animals at the zoo or paintings at the art museum—something to engage with, wonder about, think about. There is so much thought of ‘what’s to be learned here.’”

Visitor expectations play a powerful role in learning. When there is a match between visitor expectations and the museum experience, this can lead to enhanced learning. However, exhibits that do not provide right answers or clearly lay out the steps to exploration may be challenging to visitors who come expecting to learn something new. Similarly, sophisticated tools may be intimidating to visitors who are not familiar with them. In her article “Memory, Distortion, and History in the Museum,” Susan Crane explored how exhibits that do not meet visitors’ expectations of being educated can leave visitors feeling angry or

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226 Ted Ansbacher, telephone interview by author.
227 Falk and Dierking, Learning from Museums, 117.
defrauded, yet they can also offer “visitors the opportunity to create new meanings for themselves.”\textsuperscript{228} The visitor response depends on their motivation and interest in the exhibit. When the exhibit poses questions that the visitors themselves are interested in solving, frustrations they feel may increase their motivation to find the answer. Without this level of interest and engagement, frustration can simply cause visitors to move on to the next exhibit that catches their eye.

Several factors can contribute to the success of these experiences. Interviews and evaluation results both reveal that facilitation is a key factor in creating effective laboratory exhibits insofar as visitors are thereby guided through the inquiry process. Joshua Gutwill, Senior Researcher at the Exploratorium, has found that it is very difficult to get visitors to make predictions or hypotheses using stand-alone interactive exhibits.\textsuperscript{229} Visitors have an immediate urge to try something, and it can be challenging to slow them down and get them to think about their expectations before they do so. The facilitation in laboratory exhibits—either through human interaction or multimedia—may enable visitors to overcome this urge and engage in a process of hypothesis formation.

\textsuperscript{229} Joshua Gutwill, interview by author.
Finding ways to connect to visitors’ lives is also essential in creating effective laboratory exhibits. The exhibits described here accomplish this in two primary ways. The first is through experiences that relate to the visitors’ daily lives—either by exploring common phenomena in everyday life (i.e., computers, cheese, or antibacterial agents) or by having visitors explore something about their own bodies. Advocates of the constructivist learning theory emphasize the importance of providing individuals with experiences that build on familiar concepts or ideas. Educational technology researcher Jeremy Rochelle described the benefits of this approach, saying, “when learning experiences are more concrete, related to familiar situations, and interactive, so-called ‘resistance’ often disappears, and students construct new concepts quickly.”

The second way of accomplishing this is using storytelling techniques to have visitors construct their own narratives. Museum educator Lisa Roberts described the educational experience in a museum as an experience of meaning-making, where visitors construct meaning “through observing, comparing, and evaluating possible versions of the world”—a process that results in the construction of narratives. She argued that museums should develop

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231 Roberts, From Knowledge to Narrative, 132.
ways for visitors to construct their own narratives about what they see in the museum environment. The laboratory exhibits that are embedded in the context of a story accomplish this by engaging visitors in the process of piecing together their own version of a story and coming to their own conclusions about what the evidence reveals.

To ensure success, it is also essential that the museum find ways to communicate to visitors that the laboratory exhibit experience is different from other experiences at the museum. This can help to reduce frustration with unfamiliar exhibit styles and encourage visitors to commit the time necessary to participate in this type of exhibit experience. Museums can accomplish this in a variety of ways. Several museums have utilized physical barriers to the laboratory space with mixed results. Some museums have found that creating an enclosed, separate space is an effective way to signal to visitors that a different kind of experience is in store for them. Creating a separate space can also increase visitors’ attention, reduce distraction, and heighten the quality of the experience for them.232 At the Science Museum of Minnesota, J. Newlin indicated that the process of entering the space and putting on a lab coat, goggles, and gloves creates a level of investment that encourages visitors to take the

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time to engage in the exhibits. Yet, other museums have found this separation to be too much of a barrier. At the Science Place, for example, the Inquiry Zone initially featured a portal gate. According to Paul Vinson, the museum removed it, however, when it became clear that “visitors viewed it as a barrier. Volunteers were in the space ready to do things and visitors were intimidated.”

Signage has also had mixed results in providing signals to visitors about the type of experience in which they are going to engage. At SMM’s Cell Lab and the Tech’s Wet Lab, signage works effectively to let visitors know how long it takes to complete an experiment. At COSI’s Gadget’s Café, visitors must sign up in advance for a time slot. While this has worked successfully in this location, sign-up sheets have been less successful elsewhere. SMM’s Experiment Benches were initially designed with sign-up sheets for 20-minute periods. The museum removed them when evaluation showed that they “were more of a barrier to the labs than an effective means of traffic control.” Pre-visit marketing is also likely to be key to preparing visitors for what to expect at the museum.

Despite the fact that these exhibits present real challenges to both museums and visitors, the examples shown here reveal that creative

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233 J. Newlin, interview by author.
234 Paul Vinson, telephone interview by author.
235 Perry, Experiment Bench Summative Evaluation, 27.
problem solving on the part of the museum can result in successful experiences. And, many in the museum field feel that these experiences are worth the extra effort. The following section details recommendations for how best to develop these exhibits to ensure that they successfully meet the goal of engaging visitors in the scientific process.
RECOMMENDATIONS

Since the late 1960s, several nationwide initiatives to improve science education have propelled science museums around the country to shift their focus from, on one end of the spectrum, imparting scientific content to, at the other end, engaging visitors in doing science. Museums have employed a variety of strategies in pursuit of this goal, from engineering focused exhibits that involve visitors in solving design challenges to laboratory exhibits that place visitors in the role of scientists conducting experiments. Evaluation results show that laboratory exhibits can have a significant educational impact on visitors, including helping them see themselves as scientists and engaging them in using scientific thinking skills. Museum professionals who have implemented these exhibits acknowledge the challenges they present, but also see the value of these experiences. As Al DeSena, former president of Exploration Place, said,

We all continue to try to figure out how to get beyond the isolated absorption of facts experience…I value [laboratory exhibits] enough that we should continue to try to explore all the variables and sort through how we can continue to improve them.236

The following recommendations are designed to assist exhibit developers who are interested in developing laboratory exhibits. Building on the

236 Al DeSena, telephone interview by author.
experiences of those who have developed these exhibits in the past, these recommendations detail a wide range of issues to consider and provide suggestions for how to develop these exhibits to successfully engage visitors in the scientific process.

1) Museums that seek to engage visitors in the scientific process should state this as an overarching goal early in the planning process and design their laboratory exhibits with this goal in mind.

Experiences that engage visitors in the scientific process, as opposed to exhibits designed to teach scientific content, are challenging to develop; visitors are often intimidated by science and unaccustomed to thinking like scientists. As a result, it is important that this be stated as an overarching goal from the earliest part of the planning process, rather than being added on as an afterthought. Stating this early on will aid developers in creating specific goals and objectives for their exhibits and will aid evaluators in determining exhibit effectiveness.

Specific goals will be different for each museum depending on how they define the meaning of engaging visitors in the scientific process and how they decide to design the exhibit. In looking at the examples described in this project, potential exhibit goals may include:

- Inspiring visitors to ask their own questions and formulate hypotheses about what will happen;
Enabling visitors to conduct experiments, ideally going on to design their own experiments;

Providing visitors with opportunities to use real scientific tools;

Engaging visitors in using scientific thinking skills, such as observing, analyzing information, thinking critically, communicating their ideas, etc; and/or

Empowering visitors to see themselves as scientists.

Having established a goal of engaging visitors in the scientific process, museums must also be clear about the impact they expect these exhibits to have on visitors and the specific objectives that they hope to accomplish. As outlined earlier in this paper, exhibit developers should not expect visitors to come away with a conceptual definition of the scientific process. Rather, these types of exhibits can provide visitors with experiences in doing science and using scientific thinking skills that can enhance their understanding of how science works.

2) Because different laboratory exhibit formats are successful at accomplishing different goals, museums should choose the most appropriate format to meet their goals.

Each of the four laboratory exhibit formats described in this paper are successful at accomplishing different goals, and each also have distinct disadvantages. Wet labs, for example, can successfully engage visitors in
in-depth science experiments, enable visitors to use real scientific tools, and empower visitors to see themselves as scientists. They can be intrinsically motivating and provide powerful opportunities for social learning to take place. Yet, they are limited by the number of visitors reached and their ability to provide open-ended experiences or opportunities for visitors to design their own experiments. Labs embedded in the context of a story are effective at having visitors use their scientific thinking skills to construct their own narratives. Due to the less intimate environment and reduced staffing levels, however, these exhibits require simpler tasks and visitors may not always grasp the full exhibit concept. Labs that are designed for frequent change are maximally rewarding for frequent museum visitors and offer opportunities for more in-depth and messier experiences. Yet, here too, there is a challenge of developing open-ended activities that are self-contained and easily changeable. Alternatively, open-ended exploration labs can involve visitors in posing their own questions and designing experiments to find answers. Yet, these exhibits tend to require more intensive facilitation as visitors are sometimes frustrated or stymied by these experiences or tend to jump ahead without engaging in the inquiry process. Museums need to assess their goals for a laboratory exhibit and select the format that is best suited to accomplish those goals.
3) Museums should strive to ensure that laboratory exhibits are welcoming to visitors.

Laboratory exhibits have the potential to be intimidating to visitors, who may be daunted by unfamiliar equipment or a laboratory setting. As Jan Dabrowski, former Science Director at the Oregon Museum of Science and Industry, said, “when I teach, I get people all the time who think they can’t do science. That’s a horrible thing to have happen to anyone. We need to build their self-confidence.”

There are a variety of ways to design laboratory exhibits so they are approachable rather than intimidating to visitors. Factors that influence this include the physical space, topic, types of activities, and visitor role. Having an attractive and appealing physical space, with good lighting and comfortable seating, can play an important role in helping visitors feel ready to engage in a laboratory exhibit. Laboratory exhibits that are situated in an open, centrally located space can attract people and entice them to participate. Creating exhibits that are physically accessible for more than one visitor at a time is also key to encouraging social interaction within these experiences.

Choosing topics that are relevant to visitors’ lives is also helpful in creating an experience that is not intimidating. Museums can accomplish

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237 Jan Dabrowski, telephone interview by author.
this by inviting visitors to look at the science of their own bodies (which can have a gross factor that increases visitors’ fascination) or at chemical reactions that are familiar to visitors in their everyday lives. Using a compelling story as an overarching theme and having visitors construct their own narrative is another way to engage visitors in the topic of the exhibition, but it is useful to offer this narrative in a non-linear format.

To create an experience where the visitor is comfortable, activities must be safe, reliable and easy to do physically. It also must be clear how all the equipment works and easy for the visitors to begin. Activities cannot require skills that the visitor is unlikely to have. Providing visitors with an easy initial activity and opportunities to increase the difficulty level can boost the visitors’ comfort level. This technique can also create intrinsically motivating experiences as visitors can increase the difficulty of their activity as they build their skills. Keeping activities simple and unmediated by technology can also increase visitors’ comfort level. As OMSI’s Jan Dabrowski said, “When I teach physics, I use plastic cups, pencils, things people have around the house, so they can see this isn’t magic.”

Finally, placing visitors in a role where they have control over the experiment but also have the process modeled for them is key. Visitors

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Ibid.
seem to greatly appreciate the sense of independence and control that these exhibits give them. At the same time, they require tools to empower them to use their scientific thinking skills. Science Museum Consultant Ted Ansbacher explains that modeling the process of science for people is essential in helping them gain the physical and mental skills they need to do science themselves. Science, like sports, is best taught not by reading books about the process but by watching others engage in the process and then trying it out. As Ansbacher said, “Museums need to be more courageous in embracing the goal of process and letting go of the goal of more traditional learning.” Techniques for modeling this process for visitors include computer guides, experienced facilitators, labels, or videos, each of which can guide visitors step-by-step through the exploration process or provide a model for visitors to emulate. For example, videos of visitors successfully engaging in inquiry activities at exhibits have been shown to trigger similar behaviors in other visitors. By providing a physically attractive and accessible space, choosing relevant topics, providing activities that offer opportunities for early success, and providing visitors with a sense of control over the process, these exhibits can make visitors feel comfortable.

239 Ted Ansbacher, telephone interview by author.
240 Ibid.
4) Museums should design their laboratory exhibits to be as open-ended as possible.

There is substantial research to suggest that open-endedness—or allowing the visitor to design their own experiments and pursue their own avenues of inquiry—is an important factor that contributes to learning. Yet, open-endedness remains difficult to achieve in many laboratory exhibit formats. My findings have shown that staff facilitation is an effective way of providing open-ended experiences. Because visitors often have little prior knowledge or experience with designing their own experiments, they need the guidance of staff to help them develop their own questions and determine ways to answer those questions.

A second way to encourage open-ended exploration is to create experiences based on studies of visitors and their inquiry paths. COSI’s Andy Aichele recommends creating a “discovery plan” for each exhibit—a sheet that describes what holds the visitors’ attention, what their most frequent questions are, and what they want to explore.²⁴¹ With this knowledge of the visitors’ inquiry paths, the museum can develop other activities or exhibits that can help to answer these questions. These additional activities can be provided both within the museum, or as the

²⁴¹ Andy Aichele, telephone interview by author.
Tech Museum of Innovation is modeling, through the museum’s website as part of an extended experience after the visitor has left the building.

Giving visitors options that appeal to their interests is another way to encourage open-ended exploration. According to Eric Gyllenhaal, Research Associate and Project Manager at evaluation consulting firm Selinda Research Associates, exhibits that have multiple points of entry for visitors of different ages and experience levels are more likely to lead to open-ended exploration. Exhibits that can engage children—perhaps through intriguing physical components—and adults—through introducing new ideas—are most likely to be successful. Gyllenhaal said, Physical experiences that are complex and rich enough can have concepts that are nested. The concepts little kids get out of it are precursors to what older kids get out of it, which are precursors to what adults get out of it….This gets people going in different directions, depending on where they are starting from.²⁴²

5) Museums should signal to visitors—both within and outside the museum—that these exhibits provide a different experience than what visitors may expect.

When developing laboratory exhibits, it is necessary to find ways to indicate to visitors that these exhibits provide a different experience than what they may expect to find in a science museum. Disconnects between the experience and visitor expectations can sometimes prevent

visitors from participating in these exhibits or can lead to frustration with the exhibit experience itself. Preparing visitors in advance for what to expect at the museum, as well as providing signals within the museum building, can help align visitors’ expectations with the actual experience provided by these exhibits.

Marketing can play an important role in helping visitors understand that some museum exhibits provide in-depth experiences and require a significant time commitment. As former Exploration Place president Al DeSena said, “there needs to be some effort to set expectations that these things are going to be there… You need to portray it in a way that is appealing and not intimidating.” Additionally, museums may benefit from targeted marketing to certain audiences that are more likely to be attracted to this type of exhibit. School groups, homeschool families, museum members, and other frequent museum visitors are key audiences to target.

Within the museum itself, there are a number of physical signals that museums can use to indicate the unusual nature of these exhibits to visitors. Among the strategies to consider are physical barriers to the exhibit space, signage, or sign-up sheets. While barriers and signage can be useful tools, they also have their limitations and my findings show mixed results with these techniques. Perhaps the most effective method of
introducing visitors to a laboratory exhibit is through staff interaction. Staff can let visitors know about both the types of activities that are available to them in these spaces and the amount of time required to complete them. They can also direct visitors to activities that are appropriate to their age level and interests.

6) Museums should train floor staff to facilitate inquiry.

Staff members can play a key role in orienting visitors to the laboratory exhibit, helping them feel comfortable with the exhibit, facilitating their inquiry process, and enabling them to design their own experiments. Yet, museum floor staff often tend to be students in part-time jobs or young people just starting out in their careers. Many of these individuals will not make their careers in the museum field. It is essential that the floor staff receive training that will enable them to guide visitors in the inquiry process. According to Science Museum Consultant Ted Ansbacher, it is essential that staff receive training to help them understand that “it is the process and not the goal, the climbing of the mountain, not getting to the top” that matters. A potential model for training is COSI, where museum floor staff participate in the same programs that are offered as teacher professional development programs.

243 Ted Ansbacher, telephone interview by author.
These programs focus on assessing the visitor and determining what kind of experience would work best for them, engaging the visitors in utilizing their scientific thinking skills, and inspiring them to ask their own questions and pursue their own avenues of inquiry.\textsuperscript{244} The Science Place’s Paul Vinson is currently working on developing short training programs that enable staff and volunteers to work more effectively with visitors. Vinson is particularly focusing on developing training in how to read visitors to assess their interest and needs, determine whether they want a structured experience or more open-ended experience, and anticipate what level of facilitation they require.\textsuperscript{245} COSI’s Andy Aichele agrees that this is necessary, saying “facilitating informal education is like retail. When do you want a salesperson to leave you alone and when do you want them to match the socks for you?”\textsuperscript{246}

Training requires an investment of time and money, and it is essential that the institution recognize the importance of this training and invest resources in it. However, according to Selinda Research Associate’s Eric Gyllenhaal, “training, in and of itself, is not enough. The institutions that have the best luck with inquiry-based learning were where they not

\textsuperscript{244} Andy Aichele, telephone interview by author.  
\textsuperscript{245} Paul Vinson, telephone interview by author.  
\textsuperscript{246} Andy Aichele, telephone interview by author.
only did training, but also provided continuous support. They had a culture of inquiry.”

7) **Museums should partner with scientists and/or teachers in developing the activities.**

Museums can gain significant benefits by partnering with working scientists or science educators in the development of their laboratory exhibits. Museums should explore partnerships with universities, laboratories, or technology companies that can provide resources and expertise to guide exhibit development. These experts can help develop appropriate experiments and find shortcuts that allow museum visitors to engage in an activity that would normally take more time than is feasible in a museum setting. Working with science educators can also provide similar benefits, particularly in developing simple, age-appropriate activities for visitors.

8) **If necessary, museums should consider reallocating staff to work in laboratory exhibits.**

Staff members are essential to creating successful visitor experiences in laboratory exhibits. But that is not the only reason why museums should place staff in these exhibit areas. These experiences have

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247 Eric Gyllenhaal, telephone interview by author.
also been shown to provide a more effective use of staff and volunteers than other experiences on the exhibit floor. The Science Place’s Paul Vinson indicated that when staff are stationed in exhibit halls, they tend to either stay back, serving as exhibit guards, or to act as encyclopedias, providing information to visitors. By placing staff in the Inquiry Zone, Vinson has found that it is easier to get staff to engage visitors in inquiry. Staff can be trained on specific activities and can more effectively engage visitors. Museums that are interested in developing laboratory exhibits but feel hampered by a limited number of staff members should consider reallocating staff members from other exhibit areas to staff their laboratory exhibit.

9) Museums should conduct front-end evaluation to determine visitors’ prior knowledge and experience with doing science, formative evaluation to determine if the activities are working and are engaging, and summative evaluation to examine the ability of these exhibits to engage visitors in the scientific process.

Museums that seek to engage visitors in the scientific process must conduct front-end evaluation of their visitors to determine their familiarity with this process. Front-end evaluation can reveal how skilled visitors are with using scientific thinking skills, such as observation, and can determine the level of guidance and encouragement they need to use those

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248 Paul Vinson, telephone interview by author.
skills. Likewise, if exhibit developers expect visitors to make hypotheses, it is important to understand their prior knowledge of a topic to determine if they have the background information necessary to formulate a hypothesis. Front-end evaluation is essential to developing an exhibit that connects with visitors and utilizes skills they already have. Formative evaluation as the project progresses can test the effectiveness of the various exhibit or activities at engaging visitors in the scientific process and getting them to use their scientific thinking skills.

It is also essential to conduct summative evaluation that specifically looks at the ability of these exhibits to engage visitors in the scientific process. Exhibit developers must define their goals in terms of behavioral outcomes which are ranked based on the complexity of the outcome and how well it serves as a sign of inquiry. Looking at previous evaluations that have examined this can be useful in defining and ranking these behavioral outcomes. Summative evaluation should also be holistic—looking at visitors’ physical, intellectual, and social engagement.

As outlined in my Findings & Conclusions, there are a range of existing evaluations and evaluation tools that can serve as models for evaluating laboratory exhibit: e.g., the Exploratorium, Science Museum of Minnesota’s Experiment Bench exhibits, and the Lawrence Hall of Science.
Exhibits that seek to engage visitors in the scientific process, such as laboratory exhibits, are an important tool in the fight to improve scientific literacy in the United States. These types of exhibits provide visitors with direct experiences in doing science. The more experience individuals have in participating in the scientific process, the better they will be able to understand how scientists come to understand our world and the more likely they will be to apply their own scientific thinking skills in their everyday lives. As Science Museum Consultant Ted Ansbacher said, “I don’t think it’s important that people know they engaged in science—that they know the words for it. The important thing is to get people engaged.”

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249 Ted Ansbacher, telephone interview by author.
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_______. “Science Thinking Skills: Seeing the Unseen.”


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Appendix A

Laboratory Exhibit Images

Science Museum of Minnesota, Cell Lab
Tech Museum of Innovation, Wet Lab
Ft. Worth Museum of Science and History, *Lone Star Dinosaurs* Science Lab
What Made the Kids Sick?, Exploration Place, Wichita, KS
Center of Science and Industry, Gadgets Café
Appendix B

Laboratory Exhibit Survey

1) Does your museum feature a laboratory exhibit (a distinct space that is accessible to the public on a drop-in basis, where visitors can use real scientific tools, conduct experiments, and role-play as scientists)?

   ____ Yes   ____ No

If yes, please continue with question 2. If no, please skip to question 20.

2) How many laboratory exhibits does your museum have? __________

(Please fill out one survey for each laboratory exhibit in your museum)

3) What is the title of the laboratory exhibit?________________________

4) What year did the laboratory exhibit open? ________

5) What is the square footage of the laboratory exhibit? _______

6a. Is the laboratory exhibit part of a larger exhibition?

   ____ Yes   ____ No

b. If yes, what factors contributed to the decision to include it as part of a larger exhibition?

7) What scientific discipline does the laboratory exhibit focus on? (check all that apply)

   ____ Biology
   ____ Chemistry
   ____ Physics
8) What kinds of experiences are offered in the laboratory exhibit? (check all that apply)

- Access to real scientific tools
- Structured, step-by-step challenges
- Opportunities for open-ended experimentation
- Opportunities to interact with staff/volunteers/scientists
- Other (please list)

9) Please briefly describe the activities offered in the laboratory exhibit.

10) How many hours per week is the laboratory exhibit available to the public? ___________

11) Is there a separate fee for visitors to use the laboratory exhibit?

- Yes  
- No  

If yes, what is the fee?________

12) How is the laboratory exhibit staffed?

- Unstaffed
- Volunteers (please list hours per week) ___________
- Paid staff (please list hours per week) ___________

13) What was the approximate capital budget for the laboratory exhibit?

14) What is the approximate annual operating budget for the laboratory exhibit?

15) What was the impetus for offering a laboratory exhibit in your museum? (please check all that apply and circle the most important reason)

- To teach the scientific process
- To teach specific science content
Strong interest by an individual (board or staff member)
Strong interest by a funder
Other (please list)

16) a. Has the laboratory exhibit been formally evaluated?
   ____ Yes   ____ No

   b. If yes, what did the evaluation examine? (check all that apply)
      ____ Effectiveness at teaching the scientific process
      ____ Effectiveness at teaching specific science content
      ____ Other (please list)

   c. Would you be willing to share your evaluation results?
      ____ Yes   ____ No

      If yes, please e-mail the results to maiawerner@gmail.com

17) What are the most successful aspects of the laboratory exhibit?

18) What would you like to change about the laboratory exhibit? Why?

19) I have defined a laboratory exhibit as a distinct space that is accessible to the public on a drop-in basis, where visitors can use real scientific tools, conduct experiments, and role-play as scientists. Is there anything you would change or add to this definition?

20) Does your museum have other exhibits that were developed specifically to engage visitors in the scientific process? Please describe them.
If your museum has a laboratory exhibit, please skip to question 24. If your museum does not have a laboratory exhibit, please continue with question 21.

21) If your museum does not have a laboratory exhibit, are you interested in developing one?

_____Yes _____No

If yes, please continue to question 22. If no, skip to question 23.

22) What factors have prevented your museum from developing a laboratory exhibit?

23) If your museum is not interested in developing a laboratory exhibit, what are the reasons why the museum is not interested?

24) Would you be willing to be contacted for additional information?

_____Yes _____No

25) Please check here if you would like your survey responses to be kept confidential________

26) Please check here if you would like to receive a copy of my master’s thesis_______

Please remember to attach a business card to the front page of the survey. Please return the survey in the enclosed self-addressed, stamped envelop by March 25, 2005.
Appendix C

Summarized Survey Results

1) Does your museum feature a laboratory exhibit (a distinct space that is accessible to the public on a drop-in basis, where visitors can use real scientific tools, conduct experiments, and role-play as scientists)?

<table>
<thead>
<tr>
<th>Yes</th>
<th>19 respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>51 respondents</td>
</tr>
</tbody>
</table>

2) How many laboratory exhibits does your museum have?

<table>
<thead>
<tr>
<th>One</th>
<th>13 respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two - Four</td>
<td>2 respondents</td>
</tr>
<tr>
<td>More than Four</td>
<td>2 respondents</td>
</tr>
<tr>
<td>No Answer</td>
<td>1 respondent</td>
</tr>
</tbody>
</table>

3) What is the title of the laboratory exhibit?

- Gadgets Café
- Wet Lab
- Inquiry Zone
- Jr. Lab
- BioLab
- The Touch Tech
- Chemistry Lab
- Soda Fountain Lab
- Exploratory Lab
- The Science Center
- The River Room
- The Field Station
- Wentz Microscope
- Chemistry Lab
- Physics Lab
- Holography Lab
- Paleontology Lab
- Biology Lab
- Watershed Lab
- Technology Lab
- Early Childhood Education Lab
- Explorazone
- GeeWhiz Geology
- SpaceQuest
- Pipette Challenge
- Biochemistry Discovery Lab

4) What year did the laboratory exhibit open?

<table>
<thead>
<tr>
<th>Prior to 1995</th>
<th>2 respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>1 respondent</td>
</tr>
<tr>
<td>1997</td>
<td>1 respondent</td>
</tr>
</tbody>
</table>
5) What is the square footage of the laboratory exhibit?

<table>
<thead>
<tr>
<th>Square Footage</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller than 100 sf</td>
<td>2</td>
</tr>
<tr>
<td>100-999 sf</td>
<td>10</td>
</tr>
<tr>
<td>Larger than 1000 sf</td>
<td>4</td>
</tr>
<tr>
<td>No Answer</td>
<td>3</td>
</tr>
</tbody>
</table>

6) a. Is the laboratory exhibit part of a larger exhibition?

<table>
<thead>
<tr>
<th>Exhibit Status</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>10</td>
</tr>
<tr>
<td>No</td>
<td>9</td>
</tr>
</tbody>
</table>

b. If yes, what factors contributed to the decision to include it as part of a larger exhibition?

- This is an oversized microscope with limited focusing power, but visitors get (often their first) a glimpse of the remarkable images scientists work with in microscopy. We wanted to provide that opportunity and to let people see the natural world through a microscope.
- Our Science Education Partnership Award (SEPA) from the National Center of Research Resources (NCRR) at the National Institutes of Health (NIH) grant required an educational component to the exhibit.
- The Café is part of the Gadgets Exhibition. Gadgets focuses on cool stuff and how that stuff works. The exhibition houses exhibits on electricity, magnetism, mechanics, technology, physical science, architecture, etc. The Café was built into the original plan, along with a 250-seat theater, the Gadgets Stage.
- In 1997, The Science Place hosted The Traveling Experiment Gallery (SMM). This exhibit/program provided the model for the laboratory exhibit, derived from SMM’s laboratory bench experiments. In 1999, we initiated a renovation of our Hands-On
Physics Gallery, which had been fabricated and installed in 1988. We used this as an opportunity to integrate a laboratory exhibit into an existing exhibit and to generate funding support for the lab bench.

- It’s in an early learner space with several themed areas.
- We draw all ages. We like to provide lab experiences for the 8-year-old to adult and have them use real apparatus.
- The River Room has eight interactive components—microscopes is just one part.
- The California State Frameworks stipulated that 7th and 8th grade students learn about the basics of DNA (such as base-pairing and transcription), but it does not touch on the application of genetics toward the field of medicine. The Genetics exhibition complements this curriculum by highlighting innovative advancements in genetic medicine, including new ways to diagnose disease, prescribe medicine, and potentially cure genetic disorders. In the Wet Lab, visitors perform genetic engineering as a real lab activity, rather than a simulated multimedia experience. In physically carrying out the experiment, they gain first-hand experience of what it’s like to produce medicine using genetic technology.
- Fun activity to introduce the public to scientific measurements using pipettes.
- The other way around. The lab is supportive of the exhibition.

7) What scientific discipline does the laboratory exhibit focus on? (check all that apply)

<table>
<thead>
<tr>
<th>Discipline</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>13</td>
</tr>
<tr>
<td>Chemistry</td>
<td>10</td>
</tr>
<tr>
<td>Physics</td>
<td>10</td>
</tr>
<tr>
<td>Paleontology</td>
<td>7</td>
</tr>
<tr>
<td>Geology/Earth Science</td>
<td>2</td>
</tr>
<tr>
<td>Astronomy</td>
<td>1</td>
</tr>
<tr>
<td>Ecology</td>
<td>1</td>
</tr>
<tr>
<td>Observation</td>
<td>1</td>
</tr>
<tr>
<td>Holography</td>
<td>1</td>
</tr>
<tr>
<td>Technology</td>
<td>1</td>
</tr>
<tr>
<td>Early Childhood</td>
<td>1</td>
</tr>
<tr>
<td>Botany</td>
<td>1</td>
</tr>
</tbody>
</table>
8) What kinds of experiences are offered in the laboratory exhibit? (check all that apply)

<table>
<thead>
<tr>
<th>Experience</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access to real scientific tools</td>
<td>17</td>
</tr>
<tr>
<td>Opportunities to interact with staff/volunteers/scientists</td>
<td>16</td>
</tr>
<tr>
<td>Structured, step-by-step challenges</td>
<td>13</td>
</tr>
<tr>
<td>Opportunities for open-ended experimentation</td>
<td>12</td>
</tr>
<tr>
<td>Ability to touch actual specimens</td>
<td>1</td>
</tr>
<tr>
<td>Opportunity to see something not seen before in common objects</td>
<td>1</td>
</tr>
<tr>
<td>Opportunity to use “cool” scientific devices</td>
<td>1</td>
</tr>
<tr>
<td>Special programs and demos by Education Staff</td>
<td>1</td>
</tr>
<tr>
<td>Compare, contrast</td>
<td>1</td>
</tr>
<tr>
<td>Distance learning via telelinks</td>
<td>1</td>
</tr>
<tr>
<td>Family group work</td>
<td>1</td>
</tr>
</tbody>
</table>

9) Please briefly describe the activities offered in the laboratory exhibit.

- Activities change monthly and range from engineering to botany to forensic science.
- It is a lab as one would find in a Jr. or High School. Activities are offered in classes and at open mode to public. It is monitored.
- A collection of hands-on chemistry experiments.
- Drawers can be opened, exposing real specimens. At selected times, staff and volunteers do demos at the associated counter.
- Hands-on access to physical science, perception and phenomena.
• Viewing slides with microscope/videoscope, doctor’s office with x-rays and skeleton, digging up dino bones.
• A microscope and video monitor and natural/common objects provided. Visitors control zoom and focus, examine objects, insects, their own skin.
• The main use is for our slime making activity, as staff-guided hands-on experiment in polymer chemistry.
• Chem experiments, working with fossils, live animals, building model watersheds, physics demos and experiments… too numerous and varied to list.
• Prepared slides can be viewed at will.
• 25 minute demonstrations (6 options); 50 minute hands-on labs (16 options); 50 minute distance learning programs (2 options); scientist presentations.
• Gadgets Café is built and themed like a restaurant. Science center guests make a reservation with the “Maitre D” at the reservation desk for a specific time, whether they would like to take-apart or explore, and number in their party. They sign a “we promise not to hurt ourselves or others” waiver. At the time of their reservation, they are taken through a cafeteria-style line to pick up an item to take apart; or alternatively through another salad bar-type line to pick up more guided experiments. They are let to a utensil stand where they pick up any special tools; basic tools are offered like salt and pepper on the tables. They are taken to their tables and they get to work. Wait staff (paid and volunteer team members) circulate and facilitate the interactions. At the end of their time, they bus their tables to the appropriate trash or leftover location and depart.
• The Inquiry Zone offers interactive experiment opportunities to walk-up visitors in the Hands-On Physics gallery, the most heavily attended gallery in the science center. Activities include: (1) make-it-take-it-home activities; (2) experiments with science equipment; (3) inquiry interactions, with the intent to stimulate observation, description, and hypothesizing skills, (4) demonstrations.
• Open-ended manipulative, some matching, some role play.
• Comparison of mass and density; examining pond water, microscope labs with various specimens, magnetism, scales and balances – how to use, many coming up in space exhibit.
• Looking at aquatic insects with microscopes.
• Visitors insert a jellyfish gene into bacteria, then transfer the bacteria to a nutrient plate. The nutrient plate is incubated overnight. Visitors can log on the next day to see a picture of their bacteria. Visitors use the same process of genetic transformation that scientists use to make medicines like insulin. Visitors use transfer pipettes, hot and cold blocks, nutrient plates, and an incubator. The experience takes 10 minutes to complete.
• Using micropipettes to transfer small volumes of liquid samples.

10) How many hours per week is the laboratory exhibit available to the public?

<table>
<thead>
<tr>
<th>Hours</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 30</td>
<td>6</td>
</tr>
<tr>
<td>30-39 hours</td>
<td>1</td>
</tr>
<tr>
<td>40-49 hours</td>
<td>6</td>
</tr>
<tr>
<td>50-59 hours</td>
<td>3</td>
</tr>
<tr>
<td>70-79 hours</td>
<td>1</td>
</tr>
<tr>
<td>80-89 hours</td>
<td>1</td>
</tr>
<tr>
<td>No Answer</td>
<td>1</td>
</tr>
</tbody>
</table>

11) Is there a separate fee for visitors to use the laboratory exhibit?

<table>
<thead>
<tr>
<th>Fee Type</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>0</td>
</tr>
<tr>
<td>No</td>
<td>19</td>
</tr>
</tbody>
</table>

Comments:
• $2 (only if they wish to take slime home with them)
• $1.25 per student for school groups
• $50 for reserved groups

12) How is the laboratory exhibit staffed?

<table>
<thead>
<tr>
<th>Staff Type</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unstaffed</td>
<td>7</td>
</tr>
<tr>
<td>Volunteers</td>
<td>10</td>
</tr>
<tr>
<td>Paid staff</td>
<td>14</td>
</tr>
</tbody>
</table>

* Many respondents selected multiple categories. One survey indicated space was staffed with the rest of the exhibition gallery.

13) What was the approximate capital budget for the laboratory exhibit?
<table>
<thead>
<tr>
<th>Budget Range</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1,000 or less</td>
<td>1</td>
</tr>
<tr>
<td>$1,001 - $10,000</td>
<td>6</td>
</tr>
<tr>
<td>$25,001 - $50,000</td>
<td>2</td>
</tr>
<tr>
<td>Over $50,001</td>
<td>1</td>
</tr>
<tr>
<td>No Answer/Unknown/Part of Larger Exhibit</td>
<td>9</td>
</tr>
</tbody>
</table>

14) What is the approximate annual operating budget for the laboratory exhibit?

<table>
<thead>
<tr>
<th>Budget Range</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>$100 or less</td>
<td>3</td>
</tr>
<tr>
<td>$101 - $1,000</td>
<td>2</td>
</tr>
<tr>
<td>$1,001 - $10,000</td>
<td>5</td>
</tr>
<tr>
<td>$10,001 - $25,000</td>
<td>1</td>
</tr>
<tr>
<td>$25,001 - $50,000</td>
<td>1</td>
</tr>
<tr>
<td>$50,001 - $100,000</td>
<td>2</td>
</tr>
<tr>
<td>No Answer/Unknown/Part of Larger Exhibit</td>
<td>5</td>
</tr>
</tbody>
</table>

15) What was the impetus for offering a laboratory exhibit in your museum? (please check all that apply and circle the most important reason)

<table>
<thead>
<tr>
<th>Reason</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>To teach the scientific process</td>
<td>15</td>
</tr>
<tr>
<td>To teach specific science content</td>
<td>11</td>
</tr>
<tr>
<td>Strong interest by an individual (board or staff member)</td>
<td>5</td>
</tr>
<tr>
<td>Strong interest by a funder</td>
<td>1</td>
</tr>
<tr>
<td>Make learning fun</td>
<td>1</td>
</tr>
<tr>
<td>Lab existed when we moved in the building and opened the museum. We remodeled.</td>
<td>1</td>
</tr>
<tr>
<td>To generate interest in science &amp; technology</td>
<td>1</td>
</tr>
<tr>
<td>To allow our visitors a chance to manipulate scientific apparatus</td>
<td>1</td>
</tr>
<tr>
<td>To give visitors an opportunity to role-play as real scientists</td>
<td>1</td>
</tr>
<tr>
<td>To give students and visitors</td>
<td>1</td>
</tr>
</tbody>
</table>
experience in a laboratory setting
Grant funded educational programming 1 respondent
Desire to offer lab experiences 1 respondent
Desire to offer family science experiences 1 respondent

16) a. Has the laboratory exhibit been formally evaluated?

<table>
<thead>
<tr>
<th></th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>5 respondents</td>
</tr>
<tr>
<td>No</td>
<td>14 respondents</td>
</tr>
</tbody>
</table>

b. If yes, what did the evaluation examine? (check all that apply)

| Effectiveness at teaching the scientific process | 2 respondents |
| Effectiveness at teaching specific science content | 4 respondents |
| Whether visitors thought they were doing real science | 1 respondent |
| Learning retention | 1 respondent |

c. Would you be willing to share your evaluation results?

<table>
<thead>
<tr>
<th></th>
<th>Number of respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>2 respondents</td>
</tr>
<tr>
<td>No</td>
<td>3 respondents</td>
</tr>
</tbody>
</table>

17) What are the most successful aspects of the laboratory exhibit?

- Having hands-on access to various fields of science that visitors don’t otherwise have contact with.
- Too soon to know.
- Interesting children in chemistry.
- The opportunity for visitors, especially young visitors to interact with staff and with visiting scientific professionals.
- That it does generate interest, as indicated by the continued and repeated use by visitors of various ages who are willing to figure out how to use it.
• Enthusiastic response by visitors to unfamiliar sights or the opportunity for adults to show children something they know about.
• Adults and kids in cooperative learning. Kids getting to use real tools. Everyone has an electronic of some sort. For those who elect to explore, a sense of accomplishment of completing a more complicated activity in a controlled environment.
• (a) Customer satisfaction, (b) flexibility of the space to deliver various content, (c) focusing staff/volunteer efforts to facilitate visitor experiences.
• Imagination and creativity, no limits.
• Just the hands-on nature of it. Plus, the adult-child interaction.
• Two heights of tables allow for younger children to use microscopes.
• It’s something everyone remembers: making slime. It keeps kids coming back. Even if they’ve been there 100 times, they love the experience of doing it themselves, of creating a slimy thing to play with. So it gets them more comfortable with chemistry, makes it more exciting.
• Open-ended scientific principles.
• They make learning fun. Visitors seem to love hands-on, “real” experimenting. We have some great teachers on staff here, plus many highly skilled volunteers (retired professors, engineers, etc.) Labs are fun—always full of excited, focused kids. (I learn something every time I visit.) People often express amazement at what we “let them do.”
• (1) Visitors perform actual experiment in genetic engineering. They come out of the experience feeling like they performed the work of a scientist. And that genetics is interesting work and that they have the ability to understand it. (2) Open to public visitors on a drop-in basis (the lab activity takes only 10 minutes and cost on $0.60). (3) The experience is self-facilitated through a multimedia program. Visitors feel like they are performing the lab activity themselves, rather than listening to someone tell them how to do it. This also allows one staff person to supervise four wet lab stations (two visitors each).
• Students and visitors experience science in a way that is not often provided by a school.
• Interaction between children and adults in performing the activities.
18) What would you like to change about the laboratory exhibit? Why

- Expand to other content areas.
- More on-going long-term experiments and just more of everything. More demos.
- The lab exhibit would benefit from additional changeable content, and greater staff time.
- To streamline its operation and make it simpler to use, i.e. the scope and video must be turned on separately.
- We intend to get more Wentzscopes.
- I would love to make old computers less dirty! We fill up 2-3 very large trash hoppers with waste, mostly computer cases, daily. I would love to add more intense chemistry and physics activities, but there is a safety issue with these numbers. The space (whole Gadgets exhibition) is high energy, which also makes it very loud.
- (a) More staffing, (b) more equipment.
- Add more activities that have set goals / challenge. Add a “wet” component.
- Add more scientific challenges to enhance public awareness.
- It needs to be updated and re-equipped. There have been no renovations since it opened in 1986.
- Refurbishment, more durable.
- More special demos. These really grab visitors’ attention and enhance their experience.
- Not much, but I would like to have funds to develop more and different activities.
- (1) I would reposition the lab counters so observing visitors can see what the Wet Lab visitors are doing. (Right now, Wet Lab visitors have their backs to any audience). (2) To ease traffic flow, I would add a restaurant style pager or electronic sign to allow waiting visitors to browse the exhibit while keeping an eye on who is next in line. (3) We are also developing a second activity where visitors will use column chromatography to purify GFP. This will extend the current activity where visitors transform bacteria with the GFP gene.
- More sound-proofing, room echoes slightly.

19) I have defined a laboratory exhibit as a distinct space that is accessible to the public on a drop-in basis, where visitors can use real scientific tools,
conduct experiments, and role-play as scientists. Is there anything you would change or add to this definition?

- Add that visitors also have the opportunity to pose question on science topics to live personnel / specialists.
- Role-play indicated inauthenticity, not-real. Is this what you are interested in?
- Some equipment might not be “real tools,” but examine some principle. Do you want your definition to reflect that?
- I would change “and” to “or” as these activities do not necessarily need to take place in tandem for science to happen on some level.
- A place where real scientific processes are examined and encouraged. The 5-step scientific method is so inaccurate in real scientific research and some teachers believe that if their students are not following it, they are not doing it correctly.
- As a scientist, “conduct experiments” seems like a reach for a “drop-in basis.” We run summer camp programs (1 week) where the kids run their own experiments; daily visitors do not.
- Possibly open-ended exploration, with or without staff guidance as appropriate, but your definition is fine.
- I would consider adding permanent programming space to this definition, even if the activity is not ongoing, or if the activity changes throughout the day. I would also suggest gathering data on what is providing facilitation, whether staff, a multimedia screen, or a handout.

20) Does your museum have other exhibits (or programs) that were developed specifically to engage visitors in the scientific process? Please describe them.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>42 respondents</td>
</tr>
<tr>
<td>No</td>
<td>20 respondents</td>
</tr>
<tr>
<td>No Answer</td>
<td>8 respondents</td>
</tr>
</tbody>
</table>

Comments on Yes Answers:

- Most geared toward observation, cause and effect, but some allow manipulation of variables that influence results.
• Yes. We have a Toy Inventing Exhibit where visitors look at toys and their inner workings and then are given simple household items to invent on their own.

• (1) Computer-based interactives where visitors role-play being genetic scientists or genetic counselors. (2) Physics exhibits that attempt to explain, describe, and engage visitors in “inquiry-based” science.

• Yes, various hands-on activities relating to space and the environment.

• Not to formally develop and test a hypothesis. It’s more subliminal—the exhibits and devices attempt to engage the visitor so that they want to test cause and effect.

• Kid City—a pre-school area (7 years and under) where children begin to explore through play the scientific process.

• Most of the exciting permanent hands-on exhibits demonstrate a particular scientific principle. I arrived here 6 months ago and we are in the process of revamping our permanent area into immersive environments.

• All the exhibits are hands-on and engaging. The following are our exhibit halls: North Carolina Biodiversity, Health, Physics, Technology, Traveling exhibit hall.

• We have a variety of units that demonstrate “wild weather” principles (wind speed, sand dunes, tornados, etc.) We have a dedicated “wild weather” room that a presenter demonstrates other principles (to school tours, mainly). We have a couple of microscopes showing insect parts.

• Yes. We have 150,000 square feet of electricity, sports, mechanics, structures, biology exhibits.

• All of our exhibits are designed to engage visitors in the scientific process. We are very small so we change our entire exhibit every three months.

• We do have a Crime Lab exhibition which allows visitors to solve a crime by conducting ten different science experiments, but these experiments are pretty rudimentary.

• Yes, flight simulators, wind tunnels, wellhead exhibits, etc.

• Yes, Decker Life Science Learning Center, Link Planetarium, Kopernik Space Education Center (scheduled public and school programs).

• Yes, we have (a) Nature’s Trading Post—visitors bring in items and based on level of detailed information they share about their
item, they get rewarded points and ability to swap for other things, i.e. fossils, rocks, shells, feathers, pine cones, etc. (b) We have a paleo lab that shares process with visitors, but it is “scientists on display” (and volunteer) not visitor participation, other than Q&A.

- Certainly some science skills, observation and hypothesis generation and testing, as well as some engineering challenges are built into different interactives. Also use of microscopes at some exhibits.
- The closest exhibit/program space we have to what you describe is a 700-square-foot program lab titled Geneius Labspace, operated by the center for outreach development at the University of Alabama in Birmingham. This structured program enables high school students to work with real lab tools to investigate sickle cells, HIV/AIDS and DNA Fingerprinting.
- Not really, our displays expose visitors to basic science principles. Our classes do engage visitors in the scientific process, but this isn’t for the general public.
- Not exhibits, but some cart activities and school programs.
- Not really. The exhibits here were designed before I arrived. I don’t know if any were originally designed to mimic the scientific process, but at least one does. We call it the shake table. Visitors build structures and test them to see if they can withstand earthquakes.
- Not exhibits, but programs, yes, which we hope to translate into portable exhibit enhancements (i.e. backpacks).
- We have many. Most related either to specific phenomena (for example how an electro-magnetic generator works or how a mechanical siren can be used to measure the frequency of a musical note).
- Yes. We have exhibits where visitors can change variables and see the effects. That’s our exhibit ideal, and we have exhibits in electricity, magnetism, microscopy, chromatography, astronomy and space exploration, mechanics, and probability that do this.
- Yes—Ball Race—two ramps, one hilly, one straight. Guests predict which ball will get to the bottom first. Can Crusher—three lever operated can crushers, each with differing length handles. Guests predict which lever will require least force to crush the can, then they test their prediction.
- We have exhibits that promote a person’s deductive process.
- Exhibit elements, using microscopes, many science programs and camps.
A sampling of our exhibits that were developed specifically to engage visitors in the scientific process: 1) Bottled Lightning: Tendrils of glowing light emanate from the center of a 20-inch diameter clear glass Plasma sphere. The visitors places their hands on the surface of the sphere allowing the tendrils of glowing light to touch, seek to ground them, as the visitors are themselves grounded. (2) Bubble Race: Consists of three 5-gallon capacity acrylic cylinders filled with either water or silicone oil. The visitor depresses a plunger to inject an air bubble into a cylinder and observes the difference in the bubble “rise time,” depending on the viscosity of liquid in the cylinder. (3) Hot Air Balloon: The visitor pushes a button that causes a spark to ignite a stream of propane gas at the bottom of a glass tube that is positioned at the bottom of the hot air balloon. The resultant hot air in the tube causes the balloon to rise. (4) Laser Spirograph: The visitor manipulates two knobs that control separate frequency generators producing audio and visual results. A red laser shoots a beam onto a series of mirrors controlled by the frequency generators to produce a red pattern, which is the sum of the two frequencies. This pattern is displayed on the front screen of the exhibit.

We have an area with several exhibits called S.O.A.R (Scientific Opportunities in Applied Research). The theme of the area is that guests role-play as scientists/engineers as they do all the activities. We have a rocket launcher, Design-A-Car, Drop Tower, Roller Coaster, and a Wind Tunnel (they do not use authentic scientific tools).

Yes, more than 50 percent of our current exhibits make use of the scientific principle, although visitors don’t consciously realize this.

Yes, our floor is laid out in the processing skills. We designed a traveling exhibit.

Yes, we have a Tech Hall that features hands-on design and invention (engineering, hydraulics, aerodynamics, and various other problem-solving, “conceive it, build it, test it, refine it, test again,” etc.)

All exhibits are specially designed to teach scientific methods and principles.

Most of our exhibits were designed to give the visitor control over their experience and what they learn. There are few instructions to direct them. They are free to develop their own questions and then experiment with exhibits to answer them. No other exhibits guide them specifically through the scientific process.
(1) Henry Lee crime scene: use molecular techniques to solve murder; (2) Barbara McClintock exhibit: learn about maize genetics; (3) Cellarium: “travel” through an animal cell.

- Physics room with balls. Earth’s fury room with natural disasters. Bubble room.
- The entire process—no; pieces of the process—yes.
- Wow. Lots. COSI is almost more process than content. We do not have too many of the typical Exploratorium (I call them Mothership) type of exhibits. Instead we have lots of stylized inquiry-encouraging exhibits with fewer labels and more need (in my humble opinion as a museum educator) for museum faculty to facilitate for deeper meaning and relations.

- (1) Raceways: balls roll down ramps and experiments with motion can happen; (2) Simple machines: apples are packed at a mock packing shed using all simple machine types. (3) Emergency room: role playing with old equipment in a hospital setting.

- Museum exhibits
- Floor demonstrations
- Yes. Lone Star Dinosaurs, Dino Dig
- Light spectrum scopes, resonance, oscilloscope, kinetoscope, robot, kaleidoscope, camera obscura, cockpit mock-up, others.

Comments on “No” Answers:

- Not yet, but in Sept. 2005, we will be opening a collections discovery gallery.
- This varies depending on one’s definition of the scientific process. Overall, the museum focuses more on engineering and the application of technology, rather than the scientific process.
- No. Most of our exhibits focus upon biodiversity, conservation, and some aspects of research done regarding local animals and plants.
- Not yet, we are in the design phase of a scientific role.
- No, our exhibits are hands-on but not focused or designed with the scientific process in mind.
- Not at current. We are creating one and have made some in the past as part of changing exhibitions.

21) If your museum does not have a laboratory exhibit, are you interested in developing one?
22) What factors have prevented your museum from developing a laboratory exhibit?

<table>
<thead>
<tr>
<th>Factor</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost/Money</td>
<td>20</td>
</tr>
<tr>
<td>Space</td>
<td>17</td>
</tr>
<tr>
<td>Staffing</td>
<td>16</td>
</tr>
<tr>
<td>Is Creating One / Part of Future Plans</td>
<td>9</td>
</tr>
<tr>
<td>Lack of Strategic Planning / Audience Research</td>
<td>3</td>
</tr>
<tr>
<td>Never Come Up</td>
<td>2</td>
</tr>
<tr>
<td>Upkeep/Maintenance</td>
<td>1</td>
</tr>
<tr>
<td>Liability</td>
<td>1</td>
</tr>
<tr>
<td>No Interested Staff</td>
<td>1</td>
</tr>
<tr>
<td>Grant Funding and Development Resources</td>
<td>1</td>
</tr>
<tr>
<td>Resources</td>
<td>1</td>
</tr>
<tr>
<td>Materials / Equipment</td>
<td>1</td>
</tr>
<tr>
<td>Time</td>
<td>1</td>
</tr>
<tr>
<td>Problem of Empty-Looking Spaces</td>
<td>1</td>
</tr>
<tr>
<td>Messy</td>
<td>1</td>
</tr>
</tbody>
</table>

Comments:

- A lack of adequate personnel to staff such an exhibit. With hands-on enclosed exhibits, we have no such problem. On exhibit person, me, can cover visitors’ interaction of the entire museum consisting of over 70 hands-on science exhibits during regular operation. When we have school groups, we require 1 teacher for every 10 students.

- Money and space. Our current facility is small. We are planning an all-new science center that will include a laboratory for classroom purposes.

- 1) Lack of staff to facilitate; we have used a different model that are learning labs, separate from exhibits and designed for school
groups. 2) The problem of empty-looking spaces when few visitors are around.

- The former museum staff did not formulate any kind of plan that would have utilized such a concept. If I understand the Lab exhibit as you describe, it would be very costly to develop, staff and maintain.
- Very staff intensive. It might be feasible on a temporary (one a month for 2-3 hours) but not full time all the time.
- We are planning an area on infectious disease and estuary studies. We are in the midst of a major expansion and these will be on the floor in 2007.
- We are just now in the process of remodeling / renovating and within it, we hope to have a laboratory exhibit as well as others in which the scientific process is used.
- We’ve only had a small gallery devoted to natural sciences; most of our “permanent” gallery space has been devoted to cultural displays. However, we are currently constructing a new Science Learning Center scheduled to open this fall. Because of the imbalance in our “permanent” galleries, a majority of our changing exhibits have been science-oriented, and pretty many of these have had lab elements.
- I don’t know that it’s something that’s been considered for recent exhibit development projects. But it’s an approach that I think might work well for a future installation of the solar telescope and the accompanying exhibit.
- Just the flow of our master plan. We are engaged in large capital projects and some of the exhibit design issues have prevented us from moving in that direction. Mostly it is an issue of staffing. We can’t design exhibits that require staff.
- Money! Big part of future plans though, including a fossil hall/biodiversity exhibit project.
- Space, budget… although a proposal for an integrated “science commons” area for hands-on activities has been endorsed.
- Space. Hope to expand in 1-2 years and then do so.

23) If your museum is not interested in developing a laboratory exhibit, what are the reasons why the museum is not interested?

<table>
<thead>
<tr>
<th>Staffing</th>
<th>7 respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not Part of Strategic Plan</td>
<td>4 respondents</td>
</tr>
<tr>
<td></td>
<td>3 respondents</td>
</tr>
<tr>
<td>---------------------------</td>
<td>---------------</td>
</tr>
<tr>
<td>Space</td>
<td></td>
</tr>
<tr>
<td>Target Age</td>
<td></td>
</tr>
<tr>
<td>Cost/Money</td>
<td></td>
</tr>
<tr>
<td>Materials / Equipment</td>
<td></td>
</tr>
</tbody>
</table>

Comments:

- Too much staff time required for prep and oversight.
- It would require supervision. Left alone, the visitors could end up hurting themselves, others, or property.
- A lab doesn’t currently fit into the museum’s plans for future exhibits. These exhibits are more self-oriented/led than a lab would be.
- Scientific equipment is too expensive and too easy to break to be left for the public to use on a drop-in basis. We already have several group programs that allow us to use scientific tools and teach about the scientific method. We are able to do this because the area is closed to the public and only people who pre-book are allowed to be a part.
- Due to budget constraints, we would not be able to construct, stock and staff such an exhibit in the foreseeable future.
- We generally do not want a laboratory for the general public because without direct staff supervision, the expensive/fragile equipment could easily be damaged by uninformed visitors.
- We are in the midst of an expansion project that includes some exhibit development based on the results of a community charette. “Laboratory” exhibit per se was not discussed.
- We have trouble keeping enough staff to help visitors with our current exhibits. We have temporary areas where more experiment-based, open-ended activities can be done, and then put away if staffing doesn’t allow it.
Appendix D

Interview Sources

Andy Aichele
Senior Director, Exhibition & Volunteer Programs
Center of Science and Industry (Columbus, OH)
Telephone Interview, April 18, 2005

Ted Ansbacher
Science Museum Consultant
Science Services (White Plains, NY)
Telephone Interview, June 17, 2005

Chris Burda
Senior Exhibit Developer
Science Museum of Minnesota (St. Paul, MN)
In-Person Interview, St. Paul, MN, February 4, 2005

Jan Dabrowski
Former Science Director
Oregon Museum of Science and Industry (Portland, OR)
Telephone Interview, April 20, 2005

Al DeSena
Former President
Exploration Place (Wichita, KS)
Telephone Interview, April 20, 2005

Joshua Gutwill
Senior Researcher
Exploratorium (San Francisco, CA)
In-Person Interview, San Francisco, CA, April 13, 2005.

Eric Gyllenhaal
Research Associate and Project Manager
Selinda Research Associates (Chicago, IL)
Telephone Interview, June 6, 2005
Chuck Howarth  
Former President  
Liberty Science Center (Jersey City, NJ)  
In-Person Interview, Oakland, CA, April 5, 2005

Johanna Jones  
Senior Associate  
Randi Korn & Associates (Alexandria, VA)  
In-Person Interview, San Francisco, CA, April 11, 2005

Anders Liljeholm  
Lead Educator, Tech Lab  
Oregon Museum of Science and Industry (Portland, OR)  
Telephone Interview, April 11, 2005

Peggy Monahan  
Former Director of Exhibits & Programs  
The Tech Museum of Innovation (San Jose, CA)  
Telephone Interview, December 7, 2005

J. Newlin  
Director, Physical Sciences and Technology  
Science Museum of Minnesota (St. Paul, MN)  
In-Person Interview, St. Paul, MN, February 4, 2005

Scott Randol  
Research Associate  
Lawrence Hall of Science (Berkeley, CA)  
In-Person Interview, Berkeley, CA, June 3, 2005

Paul Vinson  
Vice President, Programs-IMAX-Exhibits  
The Science Place (Dallas, TX)  
Telephone Interview, April 13, 2005

Charlie Walter  
Chief Operating Officer  
Fort Worth Museum of Science and History (Fort Worth, TX)  
Telephone Interview, March 23, 2005
Martin Weiss
Director of Science
New York Hall of Science (New York, NY)
In-Person Interview, New York, NY, December 21, 2005

Eric Yuan
Exhibit Developer
The Tech Museum of Innovation (San Jose, CA)
In-Person Interview, San Jose, CA, March 16, 2005
Appendix E

Sample Interview Questions

Briefly describe your laboratory exhibit.
  • When was it started?
  • What is the square footage?
  • Was it part of a larger exhibition/project/initiative?

What was the impetus for developing this space?

What were the initial goals for this space?

What kinds of activities do you provide for visitors in the space? What factors went into deciding on these activities?

Do you change the activities on an ongoing basis?

What is the budget of the project (operating/capital)? Do you have a specific funder?

What staffing levels do you have in your laboratory space?

Do you have other exhibits in your museum that were developed specifically to engage visitors in the scientific process? Please describe them.

Why did you decide to offer this as an exhibit rather than as a program?

Is there evaluation of your project available that you would be willing to share?

What have been the successes and challenges?

What does this experience add to the visitor experience that more traditional exhibits don’t provide?

What factors encourage visitors to commit the time to complete the activities?
Is it possible to design experiences that are truly open-ended experimentation? Anecdotally, do you see visitors going on and continuing the experimentation beyond the provided activities?

Do you think these types of experiences can be provided more cost effectively? How?

Do you think that attempting to engage visitors in the scientific process is a priority/trend for science museums right now? Are you seeing similar experiences cropping up elsewhere?

How do these types of experiences differ depending on the scientific discipline being taught?

What prevents more museums from providing these types of experiences?

What kind of feedback have you gotten from the museum field in response to your exhibit? Have you been contacted by others?

Do you know of any research or articles that have been written on this subject?

Who else would you recommend that I talk to?
PRODUCT

*Strengthening Scientific Literacy Through Laboratory Exhibits*
ASTC Conference Session Proposal
ASTC 2005 Conference Session Proposal

Proposal must by typed; handwritten proposals will not be accepted.

1. **Session title** Descriptive but concise.

Teaching the Scientific Process through Laboratory Exhibits

2. **Session summary** (50 word maximum). Note: This paragraph will serve as the description in the conference program. Please be clear about what your session will cover.

Nationwide, science museums are developing exhibits designed to engage visitors in the scientific process. Laboratory exhibits – where visitors can use scientific tools, conduct experiments, and role-play as scientists – are being developed in pursuit of this goal. This session explores how to best develop these exhibits in order to achieve this overarching purpose.

3. Please describe the session in more detail for the Conference Planning Committee (125 word maximum):

In an effort to improve science education, science museums across the country are developing exhibits that focus on engaging visitors in the scientific process. Laboratory exhibits are one tool in this effort. But how effective are these exhibits and how can they best be designed to accomplish this goal? Building on the findings from my master’s project, this session will provide exhibit developers with a list of issues to consider and a set of recommendations for how to best develop these exhibits. The session also explores various laboratory exhibit formats and outlines the best ways to evaluate the efficacy of these exhibits. Finally, through a hands-on activity, visitors will get a taste of the types of experiences that these exhibits can provide.

4. **Key issues** What are the key issues addressed by your session, and why are they important?

This session will address the following key issues:

---

250 The Call for Proposals for the 2006 ASTC Annual Conference will not be issued until August 2005. As a result, I am temporarily utilizing the 2005 Call for Proposals. When the new guidelines are issues, I will revise my proposal accordingly.
**Setting goals for laboratory exhibits:** Panelists will discuss what it means to engage visitors in the scientific process and share realistic expectations for the impact that an exhibit can have. Successful and achievable goals for exhibits must focus on providing visitors with an experience that empowers them to use their scientific thinking skills, rather than developing a thorough conceptual understanding of the scientific process.

**The advantages and disadvantages of various laboratory exhibit formats:** The session will explore four different laboratory exhibit formats – wet labs, labs that are embedded in the context of a story, labs designed for frequent change, and open-ended exploration labs. Each format has its own advantages and disadvantages. Exhibit developers need to understand the advantages and disadvantages of each format in order to select the format that will be most effective at accomplishing their goals.

**Design guidelines:** Panelists will share recommendations for how to design these exhibits to ensure that they create engaging experiences for visitors. Recommendations will focus on how to ensure that laboratory exhibits are not intimidating to visitors, how to provide opportunities for open-ended exploration, and how to prepare visitors for an experience that may be different than what they are used to.

**Administrative issues:** Panelists will discuss the administrative issues that can impact the success of these exhibits, with a particular focus on staffing. They will also share the creative strategies they have used to overcome the very real constraints of funding, staffing, and space limitations.

**Evaluation:** Panelists will discuss the value of front-end, formative, and summative evaluation in the development of these exhibits. This segment of the session will focus on how to best evaluate these exhibits to determine their ability to engage visitors in the scientific process. Discussion will focus on setting behavioral objectives and conducting holistic evaluation of these exhibits.

5. **Session Leader/Facilitator (must work for an ASTC-member institution or company)**

**Presenters’ Registration Fees:** Please note that all session leaders and presenters who are employed by an ASTC-member institution must register and pay the registration fee for the ASTC Annual Conference. For presenters not employed by a member institution, ASTC waives the registration fee for the day of their session only; however, these presenters
are required to complete a registration form and pay for any ticketed events on that day.

Name: Maia Werner  
Job Title: Exhibit Developer
Institution: Gyroscope, Inc.
Mailing Address: 620 Third Street
City: Oakland  
State: CA  
Zip: 94607
Country: United States
Phone: 510-986-0111  
Fax: 510-986-0222
E-mail: maia@gyroscopeinc.com

6. Other Presenters/Facilitators: Name, job title, institution, city/state, & session contribution.

<table>
<thead>
<tr>
<th>Confirmed</th>
<th>Tentative</th>
</tr>
</thead>
</table>
a. J. Shipley  
Exhibit Developer  
Science Museum of Minnesota  
St. Paul, MN  
J. Newlin is the exhibit developer for both the Cell Lab and the Experiment Bench exhibits at the Science Museum of Minnesota. In this session, he will primarily be focusing on the development of wet lab experiences. He will share the goals and objectives of the Cell Lab exhibit, its successes and challenges, and recommendations for developing successful wet lab experiences.

b. Charlie Walter  
Chief Operating Officer  
Fort Worth Museum of Science and History  
Fort Worth, TX  
Charlie Walter has overseen the development of several laboratory exhibits that are embedded in the context of a story, including Whodunit? The Science of Solving Crime and Lone Star Dinosaurs. He
will share the goals and objectives of these exhibits, their successes and challenges, and recommendations for developing laboratory exhibits in the context of a story.

c. Paul Vinson [X]
Vice President, Programs-IMAX-Exhibits
The Science Place
Dallas, TX

Paul Vinson oversaw the development of The Science Place’s Inquiry Zone, a laboratory exhibit designed for frequent change. He will share the goals and objectives of this exhibit, its successes and challenges, and recommendations for developing laboratory exhibits that are designed to change.

d. Andy Aichele [X]
Senior Director for Exhibition and Volunteer Programs
Center of Science and Industry
Columbus, OH

Andy Aichele oversaw the development of COSI’s Gadgets Café, an open-ended exploration lab where visitors can explore the inner workings of electronic devices. Andy will share the goals and objectives of this exhibit, its successes and challenges, and recommendations for designing open-ended exploration labs.

e. Johanna Jones [X]
Senior Associate
Randi Korn & Associates
Alexandria, VA

As a Senior Associate at evaluation firm Randi Korn & Associate, Johanna Jones led the evaluation of the Cell Lab at the Science Museum of Minnesota, the Wet Lab at the Tech Museum of Innovation, and the Lone Star Dinosaurs exhibition at the Ft. Worth Museum of Science and History. She will discuss how to best evaluate laboratory exhibits to ensure that they are meeting the goal of engaging visitors in the scientific process.
7. [X] Basic session  Check if this session will provide a basic understanding of a topic.

8. What style of presentation will you use in the session? Select one.
   | Forum | [ ] Guest speaker
   | Workshop | [X] Panel
   | Roundtable | [ ] Commercial Session
   | Showcase | [ ] Speaker’s Forum
   | Other: please specify

Room set-up
   | Theater style | [X] Round tables | Other: please specify

Single Session (1 hr. 15 minutes)

9. Key Words: Number up to three key words (1, 2, 3) that best describe your session. Use “1” for most important.
   | Accessibility/Diversity/Equity | Outreach
   | Administration/Finance | Planetariums
   | CEO/Director/Trustee | Public Relations
   | Development/Fundraising | 3 Research and Evaluation
   | Education | Teacher Education
   | Exhibit Development | Theater/Demonstrations
   | Films/Simulators | Visitor/Customer Services
   | Human Resources | Volunteers
   | Marketing | Web/Electronic Communications
   | Membership | Youth Programs
   | Mission/Philosophy | New and Expanding Centers

10. Submitted by: Maia Werner

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E-mail: maia@gyroscopeinc.com

E-mail proposals to: conference@astc.org
Save the document, complete all information and then attach to the email for quicker processing.
Mail

Deadline: December 17, 2004
Goals

This chart identifies the relative strengths and weaknesses of four common laboratory exhibit formats. The ratings indicate how successful each format generally is at accomplishing the corresponding goal. This chart is intended as a tool to assist exhibit developers in decision making about laboratory exhibit formats.

<table>
<thead>
<tr>
<th>Laboratory Exhibit Formats</th>
<th>Strengthen Scientific Thinking Skills</th>
<th>Provide Opportunities for Visitor-Designed Experiments</th>
<th>Constructivist</th>
<th>Emphasize Social Engagement</th>
<th>Integrate Multiple Engagement in Complex Tasks</th>
<th>Use Real Scientific Tools</th>
<th>Serve Large Numbers of Visitors</th>
<th>Serve Frequent Museum Visitors</th>
<th>Activities are Easy to Update</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Labs</td>
<td>Med</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>Low</td>
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<tr>
<td>Labs Embedded in the Context of a Story</td>
<td>High</td>
<td>Low</td>
<td>Med</td>
<td>High</td>
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<td>Med</td>
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<td>Low</td>
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<tr>
<td>Labs Designed for Frequently Changing Activities</td>
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<tr>
<td>Open-Ended Exploration Labs</td>
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<td>High</td>
<td>Low</td>
<td>Med</td>
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<td>Low</td>
<td>High</td>
<td>Med</td>
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</table>