STEM in Children’s Museums
Charlie Trautmann, PhD, and Janna Doherty
Museum of Science, Boston
Widely available STEM content offers many opportunities for introducing concepts through exhibits, programs, and activities. The content matter for Science, the “S” in STEM, spans from astronomy to zoology. Technology includes materials and objects that range from tiny devices to software to huge facilities, which can encompass building structures, water play, and working with model trains and traffic signals. Engineering includes concepts such as strength, flexibility, and balance, plus the design of things that people use. Math includes geometry, numbers, and patterns, among many other concepts. All of these STEM content areas can find a home among the exhibits, programs, and events of a children’s museum, and endless print and online resources provide ideas for creative staff who wish to include STEM in their offerings.

However, research on learning has shown that developing activities with the goal of simply teaching content, including STEM, can actually be counterproductive in the preschool years. There is little research showing that rote acquisition of STEM facts...
Children’s museum visionary and pioneer Michael Spock died on December 7, 2018 in Chicago after a long illness. Mike’s groundbreaking work at the Boston Children’s Museum led to the birth of children’s museums as we know them and a revolution in the broader museum world. Son of renowned pediatrician Dr. Benjamin Spock, Mike was dyslexic and struggled to read and write but found refuge in New York museums where he could wander among objects at his own pace. These early experiences inspired his later work focused on interactivity and engagement for visitors of all ages and abilities.

Chronicled in his final book/website project, Boston Stories, Mike detailed how he arrived at the Boston Children’s Museum in 1962, in his words, “without a clue.” But he soon found a direction and together with a team of like-minded rebels questioning the very definition of a children’s museum, led the transformative work of designing a museum “for somebody, not about something.”

“What was going on here? It looked wonderfully playful but was real learning going on? Parents and teachers and staff didn’t know exactly what to call it or how to describe it but a thoughtful observer could see that children were deeply engaged and that something significant was going on. At that time there were no obvious models to point to. It didn’t look much like a “real” museum but nevertheless it offered iconic experiences with real objects. And if it certainly didn’t look like a school you had to concede there was important and lasting learning going on. In some ways a new category of educational organization was being created before our eyes; not so much by grand design as by our watching kids and seeing what they were doing and enjoying, or by playing with ideas that we thought up ourselves, or by expropriating other’s promising inventions we found lying about, or by exploiting vivid memories of our own childhoods that seemed to suggest exhibits and programs we could develop.”

In the early 1980s, Mike led the relocation of the children’s museum to a dilapidated warehouse in downtown Boston where it ultimately contributed to the redevelopment of the waterfront as a cultural destination. Inspiring generations of museum leaders, in 1988, he received the American Alliance of Museum’s prestigious John Cotton Dana Award for leadership.

Mike was known for his generosity, his compassionate and supportive leadership, and his enthusiasm for the world around him. He was relentless in his pursuit of a goal, overcoming enormous obstacles—often in unorthodox ways.

Through a lifetime of professional and personal triumphs and setbacks, Mike remained courageous, optimistic, and humble. He cherished his family, friends, and colleagues. His warmth and sense of humor rarely failed. In the last couple weeks of his life, he did one of his favorite things—visited a museum, the Field Museum, where he had served as public programs director for eight years, with his family. Mike changed the way people thought about museums.

He invited people in and opened up a world of rich experiences for children and families. He changed the field, and along the way, touched many hearts.

—ED
An Interview with physicist/children’s book author Chris Ferrie

Chris Ferrie is a senior lecturer at the University of Technology, Sydney (Australia) and the Centre for Quantum Software and Information. His research interests include quantum estimation and control, and, in particular, the use of machine learning to solve statistical problems in quantum information science. Ferrie obtained his PhD in Applied Mathematics from Institute for Quantum Computing and University of Waterloo (Canada) in 2012. Ferrie’s passion for communicating science has led from the most esoteric topics of mathematical physics to more recently, writing children’s books. The father of four children, he has twenty-seven titles to date, including Quantum Physics for Babies, Block Chain for Babies, and ABCs of Engineering.

Why did you start writing science books for “babies”?
I wanted to read something about physics and mathematics to my own children. At the time (2017), there wasn’t anything available. So, I wrote some myself!

Who is the audience? Who do you think about when you’re writing?
The primary audience is parents of young children. While I don’t think any particular group is excluded, I hope the books are most useful to those parents who have some anxiety about math and science. The most likely consumer understands the importance of literacy but is also looking for a unique gift for a friend or family member. Until recently, not many children’s bookshelves had quantum physics on them.

When constructing the books, I imagine a parent attempting to read to a typical one year old. The illustrations should be simple and eye-catching, and the sentences should be easily spoken and understood by the parent.

Many people think science is “too hard,” they can’t learn it. But your books take very complex subjects such as quantum physics and boil them down to key, basic, but easily understood (mostly) elements. How do you decide which topics to focus on?
I intentionally choose topics seen as the most difficult, because they often come with an air of mystery for the same reason. For example, trigonometry is considered hard, but only in the sense that it is time-consuming and tedious to solve Year 10 (comparable to ninth grade in a US high school) homework problems. Quantum physics is seen as intrinsically hard—that it is somehow reserved for the best and brightest. However, some aspects of quantum physics are taught to Year 10 students (recall the Bohr atom from your chemistry class). In fact, trigonometry and quantum physics are equally difficult. Both take time and practice to master. The longer you study them, the more nuanced your understanding becomes. But even if you’ve gotten to that point, you had to start somewhere.

How do you test the material to be sure readers understand your explanations?
The books are tested with various audiences, including adult experts and nonexperts. My wife, Lindsay, will often be the first to test them out with our children, ages eight and under. I don’t treat these as focus groups where I ask the readers to rationalize their responses. If my children are engaged with the pictures, point, ask questions, repeat things, and so on, then I know something is working.

What do you hope readers take away from your books?
Specific to each topic, I hope readers realize there is far more to the world than presented directly to our senses. I hope parents feel less mystified by these seemingly complex topics. I hope these books entice parents to continue reading and exploring science with their children.

I hope parents read my books to their children with excitement, enthusiasm, and curiosity. And I hope children feel the desire to emulate those things. I hope both parents and children engage in asking questions and guessing at answers.

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What are the differences between teaching science to adults and teaching it to kids?
The difference seems quite large on the face of it. But ultimately the only necessary change is the complexity of the language used. The principles are the same. I try to tell a story that is a continuation of what the child/parent/student/colleague already knows. That is why every book starts with “This is a ball.”

Einstein said, “The definition of genius is taking the complex and making it simple.” Has writing children’s books helped you better understand the complex scientific issues you research and teach to your adult students?

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What does it mean to do STEM in a children’s museum? Does it mean helping children engage in scientific processes, developing habits of mind such as questioning, investigating further, and seeking evidence? Or perhaps it means choosing a scientific content area, like physics, and providing different experiences for children within that domain? Or, does it mean providing opportunities to explore, play, or iterate many times within a specific environment or with a variety of materials?

How do children’s museums talk about STEM, both internally and externally? Do the conversations differ when we talk with parents, children, funders, or staff from different departments?

A Room with Many Views

Over twenty-two years in the field, I have found that one’s perception about how, when, and why children’s museums should be engaging with STEM really depends on perspective, or the individual lens through which one views the world. Of course, these lenses differ. Children may not care about STEM; young ones may not even know what it is. Yet, they actively pursue relevant, engaging, and fascinating experiences that pique their curiosity and feed their creativity. Caregivers may prioritize providing their children with opportunities to gain or advance knowledge through STEM experiences. However, they may not realize that art experiences focused on spatial relationships also engage their children with problem-solving skills critical to science and math learning. Some funders may be interested in providing youth with science career experiences, while others may prefer to invest in the interplay of science and media. Educators may care most about facilitation of STEM experiences through open-ended questioning; exhibit developers may prefer to create phenomenon-based experiences that draw children in; development professionals may want to vary the way that they talk about a given experience based on the funder they are pursuing.

Marcelo Gleiser, frequent National Public Radio science commentator and director of Dartmouth University’s Institute for Cross-Disciplinary Engagement, teaches a class he described in an episode of NPR’s “Cosmos and Culture” as one “that tries to capture the…mixing [of] the sciences, the humanities, and the social sciences as different and complementary ways of knowing the world and why we matter. … [The] class requires that scientific thinking be contextualized culturally, so that students can situate the ways in which some of the most revolutionary ideas in the past 2,000 years emerged when they did.”

Gleiser notes a “cultural split” in academia between the humanities and the sciences, referencing C.P. Snow’s original commentary on the divisions between the “literary intellectuals” and “physical scientists” in his 1959 Cambridge University lecture. In Gleiser’s view, “We have the unprecedented opportunity to bring the sciences and the humanities back into constructive engagement, as complementary and interdependent facets of human knowledge. We now face questions which cannot be examined from a single perspective: We need both a scientific and a humanistic take on things in order to further our understanding.”

Many important discoveries have been made as a result of ‘aha’ moments among people from different disciplines. Varied views of the world allow for a convergence of deep subject area knowledge sparked by creative thinking in new directions, from multiple perspectives. For instance, one positive solution to the climate change dilemma is the recognition of “ecosystem services,” quantifying the value of nature to humans, which leverages the combined strengths of environmental science and economics. The eradication of smallpox in the early 1970s was successful as a result of a combination of doctors, public health officials, and transportation specialists working across borders and in collaboration with corporate leaders in India for medical and cultural innovative solutions.

Playing at the Intersections

Jenni Martin
Children’s Discovery Museum of San Jose

A Children’s Discovery Museum of San Jose exhibit features a set of real traffic lights that can be manipulated to control actual traffic lights outside the museum.

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Children’s Discovery Museum of San Jose

So, what does this mean for how children’s museums should engage with STEM? At Children’s Discovery Museum of San Jose (CDM), we play at the intersections—literally. Our museum features a set of real traffic lights and crosswalks. Children practice pushing the button, waiting for the light, and crossing to the other side. But there’s also a switching station, programmed with working algorithms, that operates the actual traffic lights on the street outside the museum. Manipulating wires to simulate changing the patterns, children can see a timing station in action.

Without question a role-play activity, it is also an opportunity to interact with others, capitalizing on the social context of the children’s museum environment, where people from many different backgrounds come together to make sense of the world.
together. It is also a science activity: as they play, children ask questions and experiment with different configurations to find out more. They engage their curiosity and their creativity. In fact, the museum’s mission is to inspire curiosity and creativity so that today’s children become tomorrow’s visionaries. This really is about playing at the intersections of content and process, of art and science, of individual learning and learning within a social context.

More Than Four: STEM+

What if the natural niche for children’s museums and STEM is that overlap between the sciences and the humanities? What if we actively consider, in each experience that we develop for children, how curiosity is sparked and creativity practiced? What if, through exhibit and program development, we consciously engage children and their caregivers to consider ideas or phenomena from different perspectives, providing experiences that encourage them to interact across disciplines? How might we do this? Without having all the answers, I offer these topics for exploration.

RELEVANCE

Start with familiar, fascinating, approachable experiences that are relevant to children and to their caregivers. Then provide the spark or twist that helps children, and their caregivers, see that phenomenon, material, or natural object in a new light. Build from what they already know and offer a new way of thinking. In CDM’s Waterways exhibition, visitors are immediately captivated by a stream of water shooting up toward the ceiling, strong enough to balance a small plastic ball. Children are familiar with water that they drink, bathe in, or experience as rain, but this display of powerful and focused water is a definite twist, which almost always prompts them to ask, “Hey, how does it do that?”

In Waterways, children explore a familiar substance, water. Experiencing its power in a new light is always fun and leads them to question how it can do that.

ACCESS

Consider access more broadly, taking into account physical access, access for different ages and cognitive levels, access from different cultural and linguistic perspectives, etc. In the exhibit and program development process, develop and then look again, asking, how might we expand the access without losing the experience’s original intent? Could increased access expand the depth of the experience as well?

CDM’s Secrets of Circles exhibition features signage in three languages (Spanish, Vietnamese and English) with accompanying images drawing from Mexican and Vietnamese cultural traditions. Summative evaluation indicated that for families of Vietnamese and Mexican descent, the signage was important and relevant to their experience of the exhibit. In addition, for caregivers not from either of those two linguistic and cultural groups, the opportunity to experience photos, traditions, and language from Mexico and Vietnam was also highly valued as a way to introduce a global perspective to children.

RESEARCH

Continue to invite learning researchers to help us understand how children and their caregivers are using and learning from what we have developed. In CDM’s work with developmental psychologists, we have gained a number of different and important perspectives, which we now consider as we develop new exhibits. The work of Dr. Maureen Callanan, developmental psychology professor at the University of California, Santa Cruz, has helped us to understand that some caregivers who do not consider themselves content experts in science adopt a co-learner approach when exploring science exhibits with their children. Now when we develop our signage, we ask, have we acknowledged and honored this perspective? Through the work of Dr. Kevin Crowley, professor of Learning Sciences and Policy at the University of Pittsburgh, we have learned that children as young as four years old can become deep content experts in dinosaur knowledge. Now when we develop multiple access points for any exhibit experience, we ask, have we provided something for those already very knowledgeable to go even deeper in their learning?

REFERENCE

There is also the question of how we refer to STEM in our signage and collateral materials. What are the pros and cons to using the word “science”? Early in my career, when facilitating inquiry-based experiences for children, I learned that if I did not mention they were engaged in science experiments, most children did not characterize what they were doing as science. Conversely, when I facilitated STEM professional development with afterschool care providers in the early 1990s, their anxiety levels increased and self-confidence plummeted when I told them that we were going to do science activities. This reaction may also be the case with some museum staff and parents who are uncomfortable with science. Is there a way to build self-confidence with-

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Creating a STEM Learning Ecosystem
An Interview with Dennis Schatz, Pacific Science Center

Interviewed by Marcos Stafne, Montshire Museum of Science

Dennis Schatz is senior advisor at Pacific Science Center in Seattle, Washington, and senior fellow at the Institute for Learning Innovation. Recently elected president of National Science Teachers Association (NSTA), Schatz is also a member of the board of BSCS Science Learning and a technical advisor to the Smithsonian Science Education Center (SSEC). A research solar astronomer prior to his career in science education, he worked at the Lawrence Hall of Science at the University of California, Berkeley, prior to moving to Seattle in 1977, where he has held a variety of positions. Schatz was a visiting scholar at the University of Queensland, Brisbane, Australia, and served for four years as a program director at the National Science Foundation (NSF). Schatz is the principal investigator for a National Science Foundation (NSF) grant to develop a Professional Learning Framework for informal science education professionals that will help practitioners better understand the knowledge, skill, behaviors, and attitudes needed to be effective.

In 2007, he founded the Portal to the Public program that developed and researched models for science-based professionals to engage with public audiences via face-to-face interactions to help the individuals understand current science research and its application.

His many honors include the renaming of Asteroid 25232 to Asteroid Schatz by the International Astronomical Union in recognition of his leadership in astronomy and science education. He has received numerous awards from NSTA, including the 1996 Distinguished Informal Science Educator Award and the 2005 lifetime achievement award (Distinguished Service to Science Education). He is also the only non-CEO or public official to be named an ASTC Fellow.

Schatz is co-author/editor of several curriculum resources, including his most recent teacher resource book, Solar Science, published by NSTA. Finally, he is the author of twenty-six science books for children, which have sold more than two million copies worldwide and are translated into twenty-three languages.

STAFNE: What sparked your interest in science as a young child?
SCHATZ: I blame my brother. He’s four years older than me. As a young child I did whatever he did, and he was always active in science fairs. My seventh grade science fair project was relatively successful, advancing to the regional competition. In ninth grade, I wrote to consulates all over the world asking them to collect debris from their gutters to send to me. I examined the dirt for micro-meteorites. My involvement with science and science fairs became my signature thing at school, ultimately getting me interested in astrophysics. That project with micro-meteorites was a great success, but was also based on what we now know is a totally fallacious premise.

STAFNE: Did your brother go into science?
SCHATZ: He became an orthodontist, a science-based profession.

STAFNE: How did your interest in science fairs lead to a career in science?
SCHATZ: Back to my brother, he said, “You have to go to a Big Ten school” because he went to the University of Illinois. The University of Wisconsin had the best astronomy department, so I applied there and got in. I later had the opportunity to work on solar astrophysics during the summer at NOAA’s Space Disturbance Forecast Center in Boulder. I then received a Fulbright grant to do solar research in Australia right after my undergraduate years. My interest in science was continually reinforced. The biggest shift for me happened in graduate school at the University of California, Berkeley. I didn’t really enjoy sitting in a cubicle in front of a computer doing hours of computations, nor did I enjoy higher-level mathematics. But I did enjoy being an astronomy Teaching Assistant, and became totally fascinated by how people learn. I was amazed that some students couldn’t understand simple concepts like seasons or phases of the moon. That led me into education and, serendipitously, becoming involved with science centers at the Lawrence Hall Science at UC, Berkeley.

STAFNE: You’ve worked in informal STEM
(Science, Technology, Engineering, and Mathematics) learning environments since the 1970s. What has kept your interest piqued in a forty-year career in informal science education?

**SCHATZ:** There is always some new activity, adventure, or project. When I left graduate school, I taught briefly at the City College in San Francisco, but that quickly felt too routine. In the informal science field there is always something new and different.

At the Lawrence Hall of Science, I worked on teaching strategies for interactive planetariums, and helped develop science activities for the visually impaired, learning from other educators who knew how to work with this group of people. When I moved to the Pacific Science Center in Seattle, I did everything from starting a new astronomy education program to being vice president of exhibits. New activities and challenges throughout my career have kept me excited and involved. Although I primarily focused on informal learning environments, at Pacific Science Center I started working closely with schools and served as co-director of Washington State LASER (Leadership & Assistance for Science Education Reform).

My career has always included working in both formal and informal learning environments. This made me appreciate that STEM learning happens everywhere. STEM learning happens in school, at home, in museums, and other places. My lifelong goal is to bridge them all together so that it becomes a learning ecosystem.

**STAFNE:** The term “STEM” has become such a touchpoint for schools and museums. Many children’s museums have STEM programming, STEM labs, or STEM departments. Over time, people have added letters to the acronym to incorporate arts, reading, and design, so now there are variations like STEAM, STREAM, and STEM-D. Does the evolution of the terminology dilute the essential focus?

**SCHATZ:** During my four years as a program officer at the National Science Foundation, I did a presentation for the more than twenty museums and other units in the Smithsonian that offer education programs. The participants included education staff from science, history, culture and arts-based organizations. STEM expanded into STEAM, and I said, “Since you do a lot of culture-based programming, you should put a C and call it SCREAM.” It got a good laugh, but I was being halfway serious. This proliferation of STEM-related acronyms makes you want to scream.

We need to get beyond looking at the labels and examine the kind of learning that is happening. Some people think that a STEM project needs to focus on just science, technology, engineering and/or math, especially when approaching a wide range of government and private funders where it can be important to use the right terminology to show you’re on board. But I believe it’s great to think broadly about STEM that includes arts, culture, and history. Rather than diluting anything, it adds a richness to STEM and shows the many avenues by which you can engage people with STEM and STEM-related concepts.

**STAFNE:** In informal or even formal STEM education preparatory programs, are the terms Science, Technology, Engineering and Math as distinct as they used to be? Or is there more of a collaboration among disciplines?

**SCHATZ:** It’s somewhere in between. They do act as independent disciplines with their own strategies for approaching problems or issues. The blended STEM acronym has allowed people to think about how the disciplines relate to the other, and at times how it’s better to combine them. You can’t really do science or engineering without mathematics, and we all use technology. I think people get too caught up in feeling pressured “to teach STEM as a combined subject.” No one should feel they’re not doing it right if they are only doing science.

**STAFNE:** I think about separating the STEM letters, and sometimes using the M as a denominator rather than being at the end, because almost all of them require some form of math. Is there one of the disciplines that doesn’t get enough attention?

**SCHATZ:** That’s an interesting question. STEM used to be SMET—mathematics was second. In science centers or children’s museums, it’s probably the mathematics that gets lost because many people are math-phobic. Sometimes it’s not clear how math fits or how math activities can be engaging. Some museums try to include it, but many use it in inappropriate or simple ways. Math is probably one of the more challenging topics to integrate into the museum world.

**STAFNE:** In my recent experience, I’ve found that many science centers are responding to the interpretation of data, especially trying to help visitors understand climate and weather. How might a children’s museum present information about data?

**SCHATZ:** Citizen science, including collecting and presenting data, is a very effective approach at the children’s museum level. For example, kids might collect climate data in their own backyards or in a museum’s outdoor exhibit. The activity certainly involves STEM, but that data is personal to them. Using experiences that are personal to the visitor, whether it is citizen science or another approach, is what is most critical.

**STAFNE:** Makerspaces or tinkering spaces, with a heavy emphasis on engineering, have become popular laboratories for STEM programming. Has the maker movement made STEM more accessible?

**SCHATZ:** Very much so. Before the maker movement, we had “make and take” activities for the visually impaired, learning planetariums, and helped develop science activities for the visually impaired, learning from other educators who knew how to work with this group of people. When I moved to the Pacific Science Center in Seattle, I did everything from starting a new astronomy education program to being vice president of exhibits. New activities and challenges throughout my career have kept me excited and involved. Although I primarily focused on informal learning environments, at Pacific Science Center I started working closely with schools and served as co-director of Washington State LASER (Leadership & Assistance for Science Education Reform).

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them together. As part of the Washington State LASER effort, we created STEM leadership institutes, bringing together teams of teachers from a number of K-8 schools to think about what it means to do STEM and how to implement STEM programs in their schools. Each teacher created their own plan for developing the STEM program within their schools. This type of planning is the exception. Most teachers are driven by individual standards—science standards, math standards, etc.—and the curriculum materials are designed to focus on each standard independently. It’s a great deal of work for any teacher, especially those lacking any science background, to actually put them all together. There’s not much time, either. Horizon Research recently reported on the amount of time the average K-3 level teacher spent on teaching individual subjects each day:

- Language arts, ninety minutes; mathematics, fifty-seven minutes; science, eighteen minutes; social studies, sixteen minutes. That’s not very much science.

**STAFNE:** In terms of accountability in science education, for the majority of the United States, science is not tested to move on to the next grade. If that were the case, you would see larger percentages of time allotted to science in the classroom. What are your feelings about that?

**SCHATZ:** Schools are held more accountable for math and language arts, so more time is spent on them. This is a big challenge for science in the STEM learning ecosystem. Schools try to cram a lot into the 180 days in a school year. So how do we make use of the entire learning ecosystem to focus on STEM or other types of learning, including social and emotional, that a person needs to develop appropriately? Out-of-school time is really critical, and that’s where museums fit in.

**STAFNE:** What are the differences between STEM learning systems in schools and those in museums?

**SCHATZ:** Schools, required by state standards to teach a variety of STEM concepts, are very focused on cognitive skills. Do students understand certain concepts? Science principals and science practices, such as how to do an experiment, are often left out. More important, our number one goal for kids should be to develop interest and enthusiasm for STEM that lasts a lifetime. Assuming students live to be eighty years old, they only spend 5 percent of their life in the K-12 classroom—and that only includes their awake hours. We want people coming out of high school saying, “Wow, I want to learn more about science.”

A number of years ago, I was sitting at a café with two people from our state’s Office of Superintendent of Public Instruction. We started chatting with our server, a high school student. My colleague, who was head of assessment, asked the server how she did on the recent science state tests. She said, “Oh, I think I did very well, but I’m just glad I never have to take science again.” She knew the concepts, she learned about force and energy, but she never wants to hear about it ever again. That’s sad, and not what should happen. This café encounter reinforced my belief that we need to use the out-of-school arena to develop interest and enthusiasm for STEM. That focus gets lost sometimes in schools with almost total focus on DCIs, SEPs and CCCs (Disciplinary Core Ideas, Science and Engineering Practices and CrossCutting Concepts) in the new science standards—they dominate what happens in schools. But that doesn’t have to happen in museums or at home.

**STAFNE:** I was an enthusiastic science student in high school until physics. My math skills didn’t match the level of expertise needed for the coursework, and I quickly lost confidence in my science ability. I got the worst grade I’ve ever received in my life, and as someone who thought of himself as burgeoning scientist, I was deflated. Then, at age seventeen, I started working at the Orlando Science Center. Walking in the first day and seeing every single physics concept played out in a fun way made me understand the concepts that I had missed in the classroom. I reconnected with my earlier science enthusiasm because of that informal learning environment. I then became even more enthused to get other people excited about physics concepts. The exhibits at the Orlando Science Center in the mid-’90s were similar to what you’d see in any family-based museum. This sparked my interest in continuing a science career through the art of science communication.

You can’t discount even the simplest exhibits in a museum—whether it be bubbles, fog, or springs—you never know how it’s going to re-engage someone with content that previously had gone in one ear and out the other. That is why I think a museum environment is well-suited to STEM learning; it makes explicit the implicit nature of science hidden in academic facts and abstractions. At home, I might not notice a spring in my pen, but in a museum environment, a spring is something to be investigated. At the Montshire, a very family-friendly, person-first science institution, we like to think about using everyday objects to make STEM come alive. How do you think museums should identify which STEM concepts to present?

**SCHATZ:** First, it depends on what the museum has available. If you have a big outdoor area, what opportunities are possible there that relate to STEM? Second, how do you develop exhibits or activities that are relevant to the visitor, whether because they are about the local environment or personally relevant? Too often, the tendency is to look at the science standards and consider what topics should be included in a program or exhibit. But that’s totally backwards. The first step should be to look at what resources and opportunities that the museum has to make a topic personal and relevant to the visitor. The challenge is how do you take what’s in any set of standards and build them personal and relevant to the individual?

**STAFNE:** When a teacher, for example, is looking for field trip opportunities, they often look at how a museum exhibit meets a standard requirement of some sort to help them to make the case for why they get to go on that visit. Do museums fall prey to “teaching to the standards”? In my career, I have heard, “Well, we have to make this exhibit because it’s the ninth grade curriculum for New York City,” or “This is smack dab in the NGSS.” What do you think about this approach?

**SCHATZ:** It’s individual to the museum, but my personal philosophy is that it is very important to be aware of local standards and respond appropriately. Obviously, when
you do a STEM-based exhibit or program, STEM concepts are involved. But it’s critical to look at what you’re hoping to present and be able to say, “Oh, this really fits nicely into our museum programs.” At the same time, part of understanding your environment is being aware of any pressures that impact the museum. If a local community is adamant that programs be totally aligned with core standards or they’re not going to support you, then that mindset must be accommodated.

The Pacific Science Center offers information that shows teachers how our exhibits align with NGSS (Washington is an NGSS state), and how they relate to specific DCIs or Science Practices. But consideration of standards is not the first step in developing our programming. Instead, our first question in developing an exhibit is, how do we make it personal and relevant to the visitor?

**STAFNE:** What’s a good example of an exhibit that stands on its own but at the same time connects to NGSS?

**SCHATZ:** I think makerspaces do a great job of figuring out ways for individuals to make the experience very personal or relevant to them. At the same time, they strongly support NGSS engineering design principles. But most museums do not design their tinkering or makerspaces with making specific DCIs and SEPs overtly visible to the users. In a school curriculum, the development process is overt: in an engineering learning activity, students might test a design, redesign it, and retest it, with attention to following engineering practices. In a museum’s Saturday making program, where youth come in for a two-to-three-hour program, educators might be more overt about the engineering design practices, but they are not bound to the same standards requirements that teachers are.

**STAFNE:** Can you think of any exemplary museum STEM programs that help to aid STEM skills acquisition in schools? Are there any studies that show how museums can make a difference that impacts students in the school environment?

**SCHATZ:** I’ve examined a fair amount of research as a senior fellow at the Institute for Learning Innovation, which pursues research into out-of-school, free-choice learning. In order for any research to be valid and reliable, it typically must be narrowly focused so that very specific outcomes can be examined (e.g., how wording on exhibit signage is more effective with girls versus boys, or how families talk about science concepts in children’s museums more with boys than with girls). Interesting research exists, but there has yet to be the definitive study of the impact of children’s museums—or any museum—on school outcomes. One could argue that museums are not doing their job because we haven’t seen improvements on all of the test scores. But this is the wrong question to ask. The better question is, how do out-of-school environments, whether they’re children’s museums, homes, libraries, etc., contribute to building a STEM learning ecosystem? Ideally, this ecosystem includes both in-school and out-of-school experiences that encourage learning of STEM concepts while also building a lifelong interest and enthusiasm for STEM.

This is what the Virginia Air & Space Center’s STEM 360 Project is trying to do. Working with twenty elementary schools in the Norfolk, Virginia, area, the project is testing outcomes by dividing fourth and fifth graders into three different cohorts, each receiving one of three different treatments. The lowest tier cohort took a field trip visit to a museum or museum outreach staff visited the school. This is a pretty typical museum-school engagement pattern. The top tier took four field trips to museums—and not just the Air & Space Center, but to other informal learning settings, such as the botanical gardens, the zoo, etc. The top tier schools also experienced four museum outreach staff visits to the school. Every family in a top tier school got a membership to the Air & Space Center, plus coaching from the center and special weekend programs. The goal was to create an immersive out-of-school environment for the top tier schools, and then to analyze four different outcomes: 1) STEM career awareness by the students (by asking them what STEM related careers they are aware of); 2) STEM engagement (do they look for science topics or STEM topics on the internet? Do they go to media and watch videos?); 3) What STEM subjects interest them? and 4) Did this program have any impact on the fifth grade science test in Virginia? The study showed positive results related to career awareness, interest, and engagement. Results related to academic achievement are still inconclusive.

There’s no question that a body of research exists that shows the importance of rich learning experiences that happen out of school. The Harvard Family Research Project, which has been doing research for more than forty years, has shown that out-of-school complementary learning opportunities are major predictors of children’s development, learning, and educational achievement. Other studies have compared urban, low socioeconomic students who do equally well in school with more affluent students, concluding that affluent students who get more extensive summer experiences don’t backslide as much as lower income students.

As the new president of the National Science Teachers Association (NSTA), my theme is to Make Science Learning Lifelong, Lifewide and Lifedeep. I’ve been developing a presentation around the evidence for the impact of out-of-school learning. All the research makes it clear that the people who have an interest in science develop it by the eighth grade, and it probably starts well before that. In those early years, children’s engagement with children’s museums, science centers, and home-based activities are all critical to becoming enthusiastic, science-literate adults.

**STAFNE:** Science museums and children’s museums can often make a great case for inspiring positive attitudes about science. Do you think that this is more important than actually “teaching” science skills in the museum?

**SCHATZ:** First of all, you can’t inspire lifelong interest and enthusiasm without learning some appropriate science concepts. I wouldn’t say that the only thing that science museums can do is to develop interest and enthusiasm. There’s no question that individuals are developing skills, knowledge, and learning concepts at the same time. The challenge with any kind of engagement, especially an out-of-school engagement, is that learning is quite variable. It’s very hard to tease out which skill/concept developed continues on page 11
Finding a pathway to encourage both learning and creativity can be tough, but the extinct realm of prehistoric life offers fertile ground for young minds in a way few other disciplines can. A simple Google search for “dinosaur” delivers more than 408-million results—a testament to the interest in this subject. However, the content of many websites leaves much to be desired, so museums, including children’s museums, and universities can often provide useful cornerstones for that virtual dinosaur hunt that parents and caregivers can trust. In turn, children’s museums know that dinosaurs are a great hook for introducing children to complex science topics.

Our understanding of dinosaurs now integrates many disciplines, not just the science of palaeontology ("ancient-life"). In recent years, palaeontology has adopted knowledge and techniques from physics, biology, chemistry, and engineering, to name a few, allowing for a new look at some very old bones. Drawing from this blossoming multidisciplinary field, museums can use palaeontology to communicate multiple strands of complex science by breaking ideas down into smaller, more easily absorbed chunks of information.

Most people come face-to-face with the remains of a dinosaur for the first time in a museum. Here is the place where the sheer size of these animals can be fully appreciated. A museum exhibit developed with the principles of object-based learning can provide additional information and interpretation, augmenting these enormous specimens with printed display panels, interactive screens, and animations. When possible, the entire experience utilizes all five senses, keeping in mind that what triggers the most successful object-based learning experience is different for each individual. In addition to exhibits, museums offer engaging education programs for both school groups and the visiting public.

An authentic object is a vehicle that can educate and permit greater exploration of the many facets of the object itself and the vast context from which it came. This object doesn’t have to be an entire dinosaur skeleton; it can be a tooth or claw (and many children’s museums have such fossils). The important thing to remember is that direct access and handling of teaching collections can aid in delivering formal and informal learning, especially when staffed by real people rather than isolated in a static display. A museum can be a place where a future palaeontologist touches a 100-million-year-old dinosaur bone for the very first time. We should never underestimate the importance of such interactions; they are powerful and lasting, as were similar experiences that reinforced the career paths for both authors of this article.

The Children’s Museum of Indianapolis (TCMI) has created an extraordinary world with these antediluvian beasts. Under a domed theater screen that reflects the ebb and flow of a prehistoric day, the Dinosphere gallery has multiple dinosaur skeletons mounted to represent Late Cretaceous (100.5 to 66 million years ago) scenes. A soundscape with a light show engages multiple senses and provides the final son et lumiere to ice this ancient cake. Dinosphere, a successful juxtaposition of current research and pure theater, is an immersive environment that draws visitors in but is still augmented by an engaging interpretation team, who take full advantage of this prehistoric stage. Finally, a Paleo Prep Lab, where families can touch real fossils and talk directly to scientists who have excavated them, furthers the multi-sensory experience.

The museum also recently announced its new Mission Jurassic project. The authors of this article are leading an international team of scientists in exploring a site in Wyoming rich with dinosaur fossils, trackways, fossilized plants, and an ancient seabed. Eventually, families will be able to visit and explore the site as well. Mission Jurassic offers the museum and its partners from the University of Manchester, Natural History Museum in London, and Naturalis Biodiversity Centre in the Netherlands a unique opportunity to inspire the next generation of explorers and scientists as we help them witness science in the making. We want to demystify science by teaching the process of science, not just the content.

Science can be like watching a race—if all you see is the checkered flag at the end, you miss the anticipation, the challenges, and the excitement of an amazing journey. We want families to see scientific exploration from beginning to end. We want to show them what palaeontologists look for in dirt and rock that is millions of years old, what they do when they discover fossilized material, and how they can use technology to uncover clues to help reveal the mysteries of history. Not only that, we want them to see how many different fields come together to create our multidisciplinary bodies of knowledge. Communicating the many steps in this process is key to understanding the results. It’s about sharing the passion we experience in the field so children can feel like they are part of the discovery, and perhaps are inspired by it to pursue a lifelong interest, or even a profession, like we have.

Children’s museums should be places where even grown-up scientists should remember the insightful words of Einstein: “Play is the highest form of research.”

Professor Phillip Lars Manning is chair of Natural History and Dr Victoria Margaret Egerton is a research fellow at the University of Manchester (UK). Both Manning and Egerton are scientist-in-residence at The Children’s Museum of Indianapolis.
Creating a STEM Learning Ecosystem

from which interaction with which child.

If you look at state assessments, schools are not doing much better. There has been very little improvement since the landmark report, A Nation at Risk: An Imperative for Educational Reform, came out in 1983 saying that the nation’s schools were failing and in need of drastic educational reforms. At the primary level, you can’t expect to develop science skills or enthusiasm by devoting only eighteen minutes a day for 180 days a year to science. (It goes up to twenty-seven minutes a day in fourth to sixth grade.) If you want to teach more science as a separate subject, you have to steal some minutes from another subject. One solution is use science as a way to teach math and literacy. But STEM learning shouldn’t be thought of just the responsibility of schools. What we need is an approach that looks at how we can capitalize on the majority of the time individuals spend out of school.

**STAFNE:** STEM integration is easier said than done. Educators need to have the right amount of professional experience and useful tools to be able to do it right. National Informal Science Education Network (NISE Net) has created a series of kits available to museums and wonderful introductions to new content. I recently attended the NISE net meeting, and I recall one educator saying, “I work in a children’s museum and I have to do the STEM programming—and I know nothing about it! These kits are helpful because they include step-by-step recipes, basically, on how to do various earth space science activities.” What do you think is a first good step for early childhood educators working in children’s museums to help prepare them to present STEM topics?

**SCHATZ:** Find out who’s doing it well and go learn from them. Try to adapt things, not invent them. When I go to the ASTC conference, my goal is to find out what other people are doing, and learn from them and adapt it as much as possible. For example, Holly Truitt at the spectrUM Discovery Area in Montana has done a great work developing STEM programming for Native Americans that connects STEM concepts with indigenous knowledge and crafts, including bead and drum making. Children’s Museum of Pittsburgh has an iconic maker-space, and they’ve been doing it for a long time. Both efforts had great articles in Connected Science Learning (csl.nsta.org), the NSTA/ASTC journal that features STEM education experiences that bridge the gap between in- and out-of-school settings.

Closer to home, what are some good things happening locally in schools, in other museums, or among nearby university researchers? People often recommend talking to professionals in STEM fields. They can be helpful for technical purposes, but they usually don’t understand the museum world very well, especially the children’s museum world. In rural areas where you don’t have access to STEM professionals, check with high school teachers. If you want to do something with biotech but you don’t know anything about biotech? There might be a high school teacher doing a biotech unit. Teachers are great resources for technical knowledge.

**STAFNE:** What’s the future of STEM learning in museums?

**SCHATZ:** It comes back to the STEM learning ecosystem: how can all museums better connect with visitors and community partners, including schools, home, and afterschool programs, to encourage out-of-school experiences? How do museums develop programs that engage visitors in the museum and then provide activities so they can take those experiences home? How can museums avoid becoming content/experiences silos, offering fee-based field trips or outreach services, driven to a large extent by the need to be financially viable? How do we think beyond that level, especially to extend the learning into homes?

Ten years ago, few places had maker-spaces. I don’t even think that word was well known yet. Now everybody has a maker-space. The STEM acronym was beginning to gain some traction ten years ago; now it’s everywhere. Is there a way that the phrase “citizen science” can achieve the same level of recognition and broad application, with museums making science more relevant and personal to visitors via citizen science approaches? I say “citizen science approaches” because I think one challenge is when museum people think of citizen science, they think of using their programming to collect data on behalf of a scientist. I’m thinking about citizen science as much more an approach that makes data collecting methodology accessible to visitors. How can museums collect data that is meaningful to their communities, and then use that data to create equally relevant exhibits or programs? This process can be as seemingly unimportant as collecting the data of how tall people are as they come through your door, adding that information to a database, and then creating an exhibit that talks about the heights of people in your community. In an outdoor nature space, there may be certain weather data, like rainfall or high temperatures, that you want your audience to measure. Not only does this data become part of the exhibit or program, but also the visitors who actively collect it become part of producing information that’s relevant not only to the local environment, but to the museum and hopefully to the visitor. How do we take that citizen science mentality and grow it in our own institutions?
Stakeholders both inside and outside the children's museum field have powered a rising tide of STEM (Science, Technology, Engineering, and Math). Families want young children exposed to this roaring engine of economic prosperity, and funders want early exposure and success to foster later STEM careers. Science and technology have become ubiquitous across children's media, with interest often driven through identifiable fictional characters and engaging narrative.

While children's museums are nimble and can quickly adapt to the pull of their audience, adding more STEM to the floor is also an opportunity to slow down and reflect. How can the unique world of children's museums—sparking wonder, blooming imagination, and fueling creativity in young learners—pull STEM into its orbit instead of the other way around? What STEM activities work especially well with young learners in our dynamic environments, and why? How can we empower families to do STEM together, recognize the curiosity of their young learners, and connect STEM activities with their everyday life and personal experience?

The National Informal STEM Education Network (NISE Net) creates educational products, including toolkits of hands-on STEM activities, covering a range of topics for a wide variety of partners including science centers, university outreach programs, and children's museums. For more than a decade, nearly 700 partners across all fifty states have successfully used these activities with diverse audiences. About a third of the partners in NISE Net are children's museums, and many more partners serve family groups with young—often very young—children. Through internal evaluation and feedback from active partners, NISE Net activity developers have made significant progress leveraging the strengths of children's museums and designing STEM activities specifically for these audiences. In this article, we step through examples from three complex, current topics: nanotechnology, Earth and space science, and chemistry, to highlight effective strategies for engaging young learners with STEM.

Nanotechnology

Nanotechnology, or the study of how the properties of matter change at the nanoscale, was the first content area covered by NISE Net—even though many advisors believed young children could not be a realistic target audience for resulting educational programming. NISE Net developers, including veterans from children's museums, decided to use the “surprise” and “wonder” of objects at the nanoscale to stimulate interest in young children. One popular strategy was to use game-like elements to help make the challenges in hands-on-activities feel more playful.

In the NanoDays activity “Horton Senses Something Small,” visitors learn that nanoscale particles cannot be seen, but can sometimes be detected by the sense of smell. Visitors listen to sections of the Dr. Seuss book *Horton Hears a Who,* about an elephant who can hear very quiet sounds that other animals can’t. To further draw children into the story, visitors wear paper elephant ears throughout the program. After using a lens to look at small things, they investigate a series of balloons with scents inside, guessing which smells come from each balloon and matching them with pictures of the smell source. Facilitators help guide caregivers to encourage young children to think of their own noses as sensitive detectors that can recognize tiny scent molecules they cannot see. At the end of the program, each child receives a scented sticker to take home, helping to extend the learning experience.

Using a fun narrative is a great way to add context and stimulate visitors’ imaginations. The *Horton Hears a Who* storybook introduces children to the idea that there is a world too small to see that can be investigated with our senses and tools—a fundamental concept of nanotechnology. The hands-on activities following the story allow young learners to develop and apply their investigative skills in an age-appropriate format. Another key part of this activity, which we will see repeated later, is its focus on real phenomena. Partner organizations reported that children were surprised and thrilled by the mystery scents from the colorful balloons. Focusing on something real
that children can investigate or manipulate is a simple but beautiful strategy to encourage STEM engagement with young learners.

Earth and Space Science

NASA, galaxies, and alien worlds will always have many young devotees. While this content is popular and exciting, it is tempting to focus on overwhelming facts about the vastness of our world, the solar system, and outer space. In collaboration with NASA, NISE Net has created Explore Science: Earth and Space toolkits with hands-on activities that focus on real phenomena, the scientific process, and visitor participation for visitors of all ages. Working closely with the Astronomical Society of the Pacific, NISE Net also updated and expanded some existing “My Sky Tonight” activities specifically for young learners.

A young visitor manipulates the path of the “sun” in the “Explore Earth: Bear’s Shadow” activity at an Earth & Space event. Shadows are a real-world, relatable phenomenon for children and a critical component of NASA science and mission planning.

In this activity, shown in the photo on this page, visitors explore shadows and the dynamic Earth-Sun system by using a flashlight and a toy bear. Young children love to take control of the flashlight and are soon gently guided by the facilitator to investigate how the bear’s shadow changes when the “sun” moves. The inviting set-up and rich materials, with a squishy sun halo around the flashlight and a colorful set of toy props, encourages children to explore STEM concepts through play. Young learners engage in science process skills here, such as making predictions, observing, comparing and contrasting, and constructing explanations. Children have agency over a safe tool, creating many different types of shadows on their own. Working alone or with a facilitator, children can begin to model the way the sun casts shadows outside through simple questions: Where is Bear’s shadow when shining the light straight down on him? How can Bear’s shadow be longer or shorter? Where is the light when Bear’s shadow is in front or behind him? Skilled facilitators can also use an experience like this to encourage children to make claims about what might happen before experiments are carried out.

Similar to the nanotechnology example, this toolkit uses a book, Moonbear’s Shadow by Frank Asch, to set context and give life to the captivating characters who assist children in the discovery process. The STEM activities in the toolkit define chemistry in terms of who uses it and why. This emphasis on people doing concrete things rather than addressing this apprehension directly. With a suite of creative hands-on STEM activities and new facilitation techniques, NISE Net developers aimed to help visitors of all ages develop positive attitudes toward learning about chemistry.

The activities in the Explore Science: Let’s Do Chemistry toolkit define chemistry in terms of who uses it and why. This emphasis on people doing concrete things rather than

Creativity Meets Science at the Children’s Creativity Museum

Images from space can be breathtaking. NASA’s Universe of Learning (NUoL), an integrated astrophysics STEM learning and literacy program, and the Children’s Creativity Museum, a core member of the NISE Net development team, recently prototyped a new space science, festival-styled event called Space Art Explorations centered around visual arts.

Thriving in the heart of a technology-driven city, the museum uses diverse programing that inspires self-expression, emotional growth, and creativity to deftly integrate STEM content from local stakeholders. Museum educators used this strategy to tell the story of nebulae—clouds of gas and dust pushed out from dying stars—that were significant factors in the formation of the solar system. NUoL content experts and museum educators noted visual similarities between the fundamental forces of nebulae and children’s manipulations of paint and wax. Nebulae mixing elements in space is essential for creating new stars, planets, and life as we know it. Children can mimic that process by swirling paint in shaving cream. To get an idea of the tremendous energy of a dying star pushing out material, children use a salad spinner to spread out paint. The twisting transformations of resulting nebulae due to neighboring gas and debris can be approximated by the random shaping of hot wax in ice cold water.

Modeled from a tested NISE Net activity template, museum educators added key science messages (e.g. “A nebula is nature’s way of mixing up materials in the space.” ), question prompts (e.g. “What colors from your nebulae art can you see in the nebulae images from space?”), and compelling science images (the Hubble Space Telescope’s image of the Cat’s Eye Nebula) that families discover in the course of the hands-on experience. Most children at the event stopped at all three activity stations described above, repeating each experience with different colors and ingredients. All visitors left with beautiful take-home creations, feeling a little more connected to far-off space phenomena.

here is real and results organically from play. NISE Net partners have reported this toolkit activity to be one of the most successful in reaching young learners.

Chemistry

Due to concerns about safety or unfamiliar science, chemistry is a STEM topic that is often last on the list for many informal educators. NISE Net, working closely with the American Chemical Society, wanted to

continues on page 22
The Bay Area Discovery Museum (BADM), in Sausalito, California, was founded more than thirty years ago to give the area’s children a better start to life. At the time, this meant creating a safe space where children could engage in age-appropriate learning experiences. Providing high-quality learning experiences to children is still the best investment a children’s museum can make to society, but as research has proven what children are capable of, what that means for the museum has evolved.

Science, Technology, Engineering, and Math (STEM) learning has become both a national focus and a hallmark of the Bay Area specifically. As a children’s museum in the heart of one of the most innovative technological areas in the country, BADM identified early on the need to share inventive, engaging programming around STEM. We wanted to transform the way our young audience experienced STEM concepts and change the way adults thought about what STEM learning was for—and who it should be for.

In 2011, in support of this goal, BADM founded an in-house research department. Its early-learning experts synthesize the latest research findings from the field to create proprietary educational assets—including an educational rationale and framework for designing early learning experiences—that are incorporated into all museum offerings. From their work, BADM has identified seven key learning goals that all children who visit the museum can achieve: Be Curious, Come Up with Ideas and Try Them Out, Make Thoughtful Decisions, Communicate Thinking, Take Risks and Persist Through Challenges, Learn to Collaborate, and Build STEM Knowledge.

With the support of our research department, BADM’s STEM offerings have grown and evolved. The more we have learned about the importance of creativity as a 21st century skill, the more we have highlighted the intersection of STEM and creativity, particularly in our Art Studios and Fab Lab exhibits.

Members and visitors primarily think of the museum as a place to have fun and share valuable family experiences, and we will always be committed to the programs, events, and exhibits they come here to enjoy. At the same time, we recognize our opportunity to make clear the STEM exploration that happens here and at our off-site locations naturally, so that caregivers recognize it while it is happening and feel empowered to continue the learning on their own.

**STEM + Creativity in BADM’s Exhibits**

Onsite, one of the museum’s most important touchpoints for STEM learning is the Fab Lab. In 2016, BADM opened the world’s first early learning Fab Lab where children ages three to ten are exposed to low-tech tools—everything from scissors to sewing machines—and high-tech tools such as 3D printers, tablets, and laser cutters. Through both unfacilitated and staffed activities, children gain confidence with tools and are encouraged to find innovative uses for them.

The introduction of the Fab Lab was not meant to usher in an “all tech, all the time,” museum mentality, nor has it evolved into that in the three years it has been open. Rather, this space was conceived as a way to respond to the increasingly digital world in which today’s children are immersed. The goal was to create a new type of balance between digital exploration and hands-on activities and to introduce children to the new relationships and possibilities emerging between the two.

In the Fab Lab, children can see 3D printers and laser cutters at work and, with staff assistance, they can use these tools themselves. Or they can get hands-on with
learning that happens during art projects, as well as tips for further engagement. For example, the header “You Can Teach STEM” was paired with the following content: “It’s easy to share STEM lessons with your child, even if you aren’t participating in traditional STEM activities. Ask them to describe the shapes they’re drawing, or to count the number of materials on the table. It’s that simple!”

STEM in the Community

BADM STEM learning is not limited to visitors who are able to make it to our physical location. The Try It Truck—BADM’s mobile engineering lab—extends the mission of the Fab Lab to off-site audiences.

In partnership with 100Kin10, a national organization committed to training and retaining 100,000 excellent STEM teachers by the year 2021, BADM participated in a design challenge with K-5 educators throughout the Bay Area. In 2013, the California State Board of Education adopted the Next Generation Science Standards (NGSS), which focus on hands-on science experiments, critical thinking skills, and lessons incorporating across scientific disciplines like life sciences, engineering, physical science, and earth and space science. Teachers implementing these standards identified the need for innovative resources and tools that would empower them to integrate engineering education and other STEM concepts into their classrooms.

During the 2018/2019 school year, the Try It Truck is projected to travel to seventy schools and twenty-four libraries, serving more than 11,500 children, as well as their teachers and caregivers. At hands-on stations, children use BADM’s “Think, Make, Try” process to solve creative challenges, such as building an object that can float on water or test original ideas, such as designing a fort. The Try It Truck is a delivery-sized vehicle that has been transformed to feature some of the same high-tech tools found in the Fab Lab, including a 3D printer and laser cutter. The BADM educators facilitating the day’s program brief teachers and adult chaperones so they feel confident supporting the children’s learning, both while the Try It Truck is at their site, and after it has packed up and pulled away.

With children as its primary audience, the Try It Truck’s programming is backed by findings from the museum’s research department on how to best introduce STEM concepts. For example, research proves that children learn best when they are intrinsically motivated and in charge of their own learning. The Try It Truck’s multiple stations feature different activities, so children can decide for themselves which stations they want to explore. If they want to spend all their time at one or two stations, they can. If they want to explore seven or eight, that’s fine too. We want the children to have fun, but also to feel that the learning is relevant to them and their interests.

The adult audience is also important. All truck programming is aligned to NGSS so that adults can see examples of creative, age-appropriate STEM learning, and gain confidence to bring it into the classroom, library, or home. Information about specific standards alignment is available to anyone booking the program, and the museum educators conduct an orientation before each program begins, so that adults understand what to look for and can be empowered to identify which activities they could recreate.
STEM Starts Early

Research proves that the experiences children have from the youngest ages build brain architecture and lay the foundation for lifelong thinking skills and approaches to learning. This is particularly significant when considering STEM success, as STEM disciplines require both content knowledge and robust thinking dispositions, such as curiosity, questioning, assessment, and confidence, when encountering new information.

Developing these thinking skills needs to begin in infancy, but most formal education settings don’t introduce STEM learning until the later years of elementary school. At BADM, we are always looking for ways to share STEM learning with our youngest visitors, starting at six months of age, and to support caregivers in recognizing what their young children are capable of.

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In our Tot Spot exhibit, reserved for children under forty-two inches tall, indoor and outdoor features provide infants and toddlers with safe areas to crawl and move around, without interruption or distraction from older children. We are now working to incorporate STEM learning experiences and vocabulary development. We are currently updating Tot Spot to include more activities that support these goals. These updates include buckets that children can dump and fill repeatedly to test theories on how many balls the bucket will hold and balls to roll back and forth with peers or a caregiver to prime children to be more helpful and generous. The new space will also introduce exhibit elements to crawl over and under that help children develop spatial language skills, linked to foundational math understanding and achievement.

Tot Spot is an obvious place for families with young children to cluster, but we didn’t want that to be the only space where this demographic could have valuable STEM experiences. In May 2018, we closed the Fab Lab for one week to rethink the space, making it more welcoming and valuable to BADM’s full range of visitors. Fab Lab’s new analog coding wall is a great example of our reimagined approach to inclusivity. A ten-year-old can use the wall’s brightly colored magnets of different shapes and sizes, arranged in different ways by our staff, to solve puzzles or logic challenges. A three-year-old, on the other hand, can use the same materials to lay the groundwork for early math concepts by exploring and learning about new shapes or recognizing patterns.

Adults are not forgotten in this space either. During programs or free exploration activities, caregivers are prompted to read explanatory signage or engage in conversation with museum educators to learn more about what their child is doing, figure out how to take elements of the activities home, and understand why the Fab Lab experience is not only appropriate, but critical for even the youngest children.

What’s Next

Since founding our in-house research department eight years ago, we have updated onsite daily programs, school and community program offerings, and other touchpoints—such as the curriculum for our museum-based preschool—to reflect their interpretations of findings on STEM learning. Even the traveling exhibits featured at the museum are selected with research in mind, and must have clear goals around engaging children in STEM concepts.

In February 2019, BADM announced an $18.5 million campus renovation to update our permanent exhibits. The museum will ultimately open five new exhibits for children ages zero to ten. To ensure these new exhibits incorporate the latest STEM learning research, the project’s architect collaborated with experts from the museum’s research department on the exhibits’ design and featured elements and activities. When complete, BADM’s reimagined campus will be the site of more transformational STEM learning experiences for children, families, and educators in the Bay Area and beyond.

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To celebrate the 25th birthday of The Building for Kids Children's Museum (BFK) in November 2017, we opened the Innovation Lab, a STEM-focused space and our first expansion in more than a decade.

The idea for the lab started years earlier. In the spirit of its namesake, our da Vinci Studio originally incorporated both art and science activities. Though the studio is large, we had more than enough ideas and projects to fill this ostensibly art-focused space. We had done STEM labs in the past, but we were ready for something permanent—a STEM-focused studio.

As we brainstormed ideas for the space, we realized we already had the perfect model: the da Vinci Studio is a hands-on, kid-led, art-focused space. Visitors love it, and frequently list it as one of their favorite places in the museum. For the lab, we wanted to create the same style of interactive space, where kids and families could explore, experiment, and create. It needed permanent interactives, as well as rotating challenges to keep the space new and exciting.

The Building for Kids is designed for kids ages crawler through eight years old. During the week, our visitors tend to be younger, lots of toddlers and preschoolers. At this age, STEM learning and activities involve counting, building, and simple science experiments. Weekends attract families with older children capable of exploring more complex STEM activities. We wanted to create one space that considered the needs, learning styles, and developmental stages of all our visitors.

Finding Inspiration

Through online research, we looked at STEM offerings at museums around the world. We visited other museums in our region to check out their interactive STEM elements. There are a lot of awesome STEM ideas out there! At the Discovery Center Museum in Rockford, Illinois, we were particularly inspired by their electricity and wind tunnel exhibits. Discovery World in Milwaukee, Wisconsin, offered some great pointers to help us set up our lab, such as putting wheels on all the furniture so everything is mobile. The Madison Children's Museum in Wisconsin has an amazing rooftop garden that includes plants, animals, and a dinosaur dig. While we were excited by the great work we saw at other museums, we were also mindful of wanting to create something unique for our community.

As a hands-on museum, the wish list for our STEM lab included a variety of interactive elements for free play, rotating table challenges to make the space different each time a family visits, and complementary programming led by a facilitator. Today, a BFK team member is always present in the lab to engage with families and help them test, evaluate, and redesign their creations such as creating parachutes to test in the wind tunnel. All of these programs and table challenges require constant planning and organization.

As we began selecting and creating different interactive and programming elements for the lab, we focused on not only what would engage kids of all ages, but also on what promoted family interaction. Building challenges are a great example. In a recent boat-building challenge, using items such as tinfoil and craft sticks, adults jumped right in to help their kids engineer a boat, and some even built their own!

Innovation Lab Emerges

Now that we knew what we wanted to happen in the lab, what should we call the space? Should we name it after a scientist? A few contenders emerged, but none stuck. Should we call it the STEM Lab? That felt too constritive, as we encourage topic overlap in all activities. Math projects in the lab may involve counting and adding colored dots to a design (visual art), while programs in the studio mix art and media (science) or create sculptures (engineering). Kids, especially young kids, don’t always notice what subject they are learning. They just want to be engaged and challenged in the process. Finally, some topics can be much more interesting when explored together. So, the Innovation Lab was born.

Erasing STEM Stigma...among Adults

One of our goals in the lab is to erase the stigma that “STEM is hard.” Though some
aspects of STEM learning are difficult and the same could be said of any topic, there’s something about math and science that is especially intimidating to some people. Soon after opening the lab, we were surprised to hear that some adults would enter the space and, after discovering its focus, tell their kids it was too advanced for them. Spotting this reaction, team members would coax the adults in. They have become very good at welcoming visitors to the space and encouraging them to try the microscope or the wind tunnel. Now that the lab has been open for more than a year, we are seeing this STEM-avoidance reaction less and less among adults.

However, we have also noticed that the “STEM is hard” recoil does not usually come from kids. Kids come in ready to experiment, whereas adults might take a little more time to warm up, sometimes concerned with getting it right. In an Innovation Lab activity, there is often no single right answer, and this can take a little getting used to. Kids often lead the way with their adults.

Adults are now starting to ask more questions, including how they can do lab activities at home. Making any kind of dough or slime is a popular program, and many adults ask for recipes. Another very popular activity is Ozobots. These little coding robots, perfect for kids of many ages, move by reading lines drawn on a piece of paper which tell the Ozobot to do different things, like speed up or turn around. Kids and adults create different patterns and designs based on what they want the Ozobot to do. The Ozobots are so popular adults ask where they can buy them, and kids come in and ask for them specifically.

Program facilitators watch what attracts kids and ask simple questions such as, “Have you done something like this before?” or “Who likes building towers?” Tuning an activity for maximum impact is more a matter of reading the crowd than simply judging them by their ages.

In any creative, kids-focused program, everything evolves. For museums interested in starting a STEM-focused space, our advice is to first define the purpose of the space. Do you want free experimentation and creation? Facilitator-led programming? Take some trips, virtual or actual, and see what other museums do. Try something out, observe, analyze, adjust, and try it again! As you try different approaches, it will become clear what works best for your visitors and your museum. Don’t be afraid to experiment. After all, that is what you are trying to encourage your visitors to do in their STEM exploration.

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STEM in Children’s Museums
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esis, designing an experiment to test it, analyzing the results, and communicating the findings effectively to others. Young scientists are often curious about concrete things, like their own body or the food they eat, from their worldview. Taking this curiosity a step further and asking children to share their reasoning for a hypothesis or observation promotes more advanced science thinking.

Technology is generally seen as the process of making something or create novel solutions or products. Building with blocks is a time-tested introduction to technology skill building. Through exhibits, programs, and events, children’s museums have many other opportunities for young visitors to learn about the process of building by using simple tools and materials.

Engineering, the third element of STEM, is a process for designing solutions to problems that involves meeting a goal while working within constraints. The photo on the cover of this issue shows students engaged with the problem: “How can we design a model windmill that will lift a cup of pennies on a string (the goal), using the materials and equipment provided (the constraints)?” Iteration, controlling variables, and persisting through failure are key elements in early engineering experiences. It is important to break down the engineering design cycle into smaller parts (build and test) or to simplify materials (paper strips, straws, and paperclips), so young children can focus on using familiar materials in new ways. This removes extraneous information and allows the engineering thought processes to come through.

Mathematics, the fourth element of STEM, is vast and influences the other three at almost every step. Math skills include the ability to count, measure, estimate, and solve problems, as well as perform other activities such as sorting a series of 3D objects by color, shape, or size, identifying patterns, or making inferences based on statistical reasoning. While these seem like complex activities, children do them every day. Children’s museums can help visitors improve their motivation and skills by providing engaging, challenging activities based on math.

While each area of STEM has a set of process skills, in reality, these skill sets overlap and reinforce each other. For example, being able to count and measure (math) is key for collecting data needed to test a hypothesis (science) or assessing whether a constructed model (technology) adequately solves a problem (engineering).

Habits of Mind

Perhaps the most important part of STEM for museum visitors is the set of habits of mind that lead children to engage with STEM in the first place, or make use of STEM later in a career or daily life. STEM habits of mind are ways of thinking that become so integrated into a student’s learning that they become mental habits. Key habits of mind associated with STEM include traits such as curiosity, creativity, collaboration, communication, confidence, critical thinking, and leadership, along with other traits such as open-mindedness, skepticism, and persistence.

Most of these traits could apply equally well to non-STEM fields, such as drama, sports, or music. So how does a children’s museum offer a program in creativity and convince parents and other stakeholders that they are supporting STEM learning?

What is STEM in a Children’s Museum?

STEM surrounds us, but the key element that distinguishes STEM in a children’s museum is intentionality. When museum staff and volunteers make connections to the STEM in a mirror, a pile of stones, a child’s scooter, or a texture wall, they transform these items into STEM exhibits. For example, a museum educator reading the “Three Little Pigs” to a child-parent group can easily turn the story experience into a STEM learning experience by asking children about the strength of various materials used to build the three houses (which of course has a big effect on whether the house will “blow down”). They can ask children about wind, the ways that they have experienced it or whether they have ever seen a tree blown over after a storm. By taking a STEM habits-of-mind approach, the educator could also discuss how experiments, teamwork, and communication could have affected the outcome of the story.

Another important way that museums can foster STEM learning is to encourage caregivers to take activities, games, concepts, and STEM habits of mind home from a museum visit. When adults engage their children in simple STEM activities (“What do you think made that burrow in our lawn?”) or daily activities (“Let’s bake some cookies together, and you can measure out two cups of flour.”), they are building STEM literacy through content, skills, and habits of mind. Celebrating moments like these during their museum visit or modeling how child-directed inquiry and play can lead to STEM learning can empower caregivers to build STEM literacy with their young learners.

How Children’s Museums Can Include STEM

Take a look at your exhibits with STEM glasses on. Observe how children and caregivers use the exhibits and materials. In what ways can you highlight STEM learning that is already happening? How can you make small (or big!) changes to enhance STEM learning? Dramatic play areas are rich with opportunities for STEM learning, as children are already engaging in narratives that help them make sense of the world and develop self-regulation, collaboration, and perspective taking—important skills for the STEM field and beyond. Play areas such as grocery stores encourage math skills (order
Playing at the Intersections
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out neglecting explicit science content? On the other hand, some caregivers emphasize scientific concepts so much they forget to allow their children to explore freely. How might we begin to bridge these gaps?

Considering access more broadly and introducing global perspectives to children, the museum’s Secrets of Circles exhibit features signage in three languages (Spanish, Vietnamese, and English) plus images from Mexican and Vietnamese cultural traditions.

INTENTIONAL CROSS-FERTILIZATION

Engaging across disciplines does not mean giving ourselves a pass on science content knowledge, or in-depth disciplinary-specific understanding. It would be a mistake to create a STEM exhibit without engaging someone with deep scientific knowledge about that content area. When CDM developed its Mammoth Discovery! exhibition about mammoth fossils discovered near the museum, we worked closely with paleontologists from UC Berkeley’s Museum of Paleontology, who ensured we delivered well-informed content. For their part, the paleontologists felt enriched by learning about how museum staff engaged younger children with paleontology concepts. Another example is My Sky Tonight a project of the Astronomical Society of the Pacific, developmental psychology learning researchers, and museums. This collaboration among astronomers who understand the physics of the sky, cognitive psychologists who study how children learn, and museum educators who have extensive expertise in informal learning environments led to a rich set of ideas tested and refined for children’s STEM learning. Capitalizing on these multiple ways of thinking, the project developed activities that were both relevant and accessible to children from different backgrounds.

Closing Message

Children draw on their knowledge and past experiences to shape their understanding of the world. They bring their whole selves to museums—their senses, cultural backgrounds, curiosity, and creativity. They also bring their family members and caregivers, and benefit when those closest to them are engaged as well. How can children’s museums provide STEM experiences that begin with something familiar and comfortable to children, and then add a new twist? What kinds of experiences allow for different access points, and encourage children and their adults to wonder, go outside what they already know, and explore further? And then, how can we encourage them and ourselves to consider the experience from different perspectives?

Children today have access to an incredible amount of knowledge at their fingertips. Nevertheless, with this access comes the challenge of navigating a rapidly changing world, with confusing social norms and interactions. Whether they concentrate on science, math, technology, literature, arts, or humanities, children benefit from exploring ideas, materials, phenomenon, and beauty in a safe and nurturing environment where they can share the joy of learning with the important adults in their lives.

As we encourage this important exploration, does it matter how we talk about it? It does. We have the opportunity, and responsibility, to showcase science concepts and shift negative attitudes about science. However, our field also needs new language to talk about today’s complexities—approaches that acknowledge broadening worldviews, global perspectives and cross-disciplinary problem-solving. We may need to discover new ways to reach across content areas, departments, differences, to find connections and build solutions. Let’s keep talking—bringing our unique perspectives and respecting the different perspectives of our visitors, funders, and staff.

As director of education at the Children’s Discovery Museum of San Jose, Jenni Martin focuses on community engagement and increasing participation in STEM by under-represented audiences. Martin is also the lead facilitator for CCLI, a partnership between Children’s Discovery Museum of San Jose, the Association of Children’s Museums, the Association of Science-Technology Center and Garibay Group, which helps museum leaders catalyze diversity and inclusion efforts in their institutions.

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The more you understand something, the more confusing it becomes. Questions lead to more questions. Eventually, you are led down the path of philosophy, asking yourself what understanding even means. That being said, viewing quantum physics, for example, from many different angles has given me an appreciation for its very complexity. I have learned that understanding a topic is best thought of in terms of layers. This gives you much less anxiety and confidence when not giving or receiving the gory details.

Can you think of anything children have said to you or asked you about your books that have led you to think about science differently?

Recently, I was struggling to explain the word “infinity” to children with little experience in math beyond small numbers. My seven-year-old said something to his brother that demonstrated an understanding of the concept. They were arguing about who had more library books. The five-year-old blurted out, “I have infinity books.” To which the seven-year-old replied, “You can’t have infinity books. If you had infinity books, you wouldn’t stop getting books.”

What are your earliest memories of your interest in science?

My parents never pushed us one way or another when it came to academic and extracurricular interests. My dad ran his own construction company, so I saw him building things all the time and it fascinated me. I still have some visible scars from trying out the saws myself.

They were both avid readers and had lots of encyclopedias and atlases that I remember spending hours reading. I did well in mathematics throughout school, which mostly came from positive reinforcement from my mum. Science per se wasn’t something that interested me. Though, I didn’t really understand what exactly the word meant.

In hindsight, I was always a scientist. I was constantly testing and breaking things, tinkering with toys and software, and observing and improving on methods of myself and others.

What are some of the next book topics you’re working on?

This year we will see economics, probability, and maybe even geography and climate science.
The “Chemistry Is Colorful” activity helps visitors explore how the process of paper chromatography helps separate mixtures and identify materials. First, visitors make a colorful pattern on filter paper, using water drops to carry pigment from water-based color markers across the paper. Next, they do the same with three black markers, and match the resulting patterns to mystery chromatograms. Children are invited to look closely at the patterns, and observe how the colors separate and mix—hopefully increasing their interest in the nature and manipulation of color. With a little yarn and a few more experiments, their chromatograms become lovely take-home bookmarks to share with friends and family, creating personal relevance. Mixing art and science by using real tools to make new creations powerfully contributes to self-efficacy, or belief in one’s own abilities, in children around STEM topics.

Conclusion

Children’s museum partners and practices are core to NISE Net’s work. Our development process and products are inspired by children’s museums’ dedication to encourage the joy of playful and experiential learning. The STEM learning strategies highlighted above nourish children’s creative minds, opening up new possibilities to spark interest in the world around them. Specifically designing hands-on STEM activities for young children, and considering different strategies that work well for the children’s museum audience, improves the experience for learners of all ages.

Everyone benefits from more creativity, more imagination, more wonder, and more play!

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Results from research conducted by the Children’s Museum Research Network (CMRN) have been featured in four issues of Hand to Hand in the past two years. CMRN articles have focused on the concept and role of play in children’s museums’ missions; the range, value, and limits of applying research in children’s museums; caregivers’ perceptions of learning and building foundational skills through play in children’s museums.

With the ultimate goal of highlighting the learning value of children’s museums, CMRN serves as a research community of practice to examine field-wide questions in the children’s museum field. CMRN studies have systematically identified key questions and protocols. Early findings have clarified some of the major philosophical and pedagogical quandaries faced by today’s children’s museums. This substantial body of work has added to the foundations of a relatively young but still growing field.

Museum practitioners have benefitted from this new knowledge. But what about the rest of the world? What is often obvious to people working in museums can be invisible to visitors. While a children’s museum’s exhibits and programs might be widely enjoyed and appreciated by children, families, teachers, caregivers, stakeholders and funders, the underlying research that supports the work is less widely known.

In 2017, CMRN conducted a study surveying visitors to eight children’s museums across the United States. One major finding of the study showed that seventy percent of survey participants reported observing something about how their children learn during their children’s museum visit, such as their learning processes, preferences, characteristics, or skills. This study underscores the importance of children’s museums as spaces that both promote children’s play-based learning and allow parents and caregivers to observe their children’s learning in unique ways.

With the goal of telling the larger story about children’s museums, CMRN has begun outreach efforts to inform the broader public, particularly parents and caregivers. The infographic (pictured left) is part of a media outreach packet conveying the findings of the 2017 study on caregivers’ perceptions of learning in children’s museums.

We asked caregivers what they noticed about their children’s learning at children’s museums.

CAREGivers LEARN NEW THINGS ABOUT THEIR CHILDREN AT THE MUSEUM.

- Learning processes
- Preferences
- Traits and Characteristics
- Skills

CAREGivers View Children’s Museums As Ideal Places to See Their Children Learn.

Caregivers stated that children’s museums are unique learning environments because of the:

- Variety of activities
- Hands-on play

Spaces designed to support learning and development

CAREGivers Noticed Their Children Learning At Exhibits And Play-Based Activities.

This gave caregivers ideas for how they might encourage their child’s interests and learning at home.

The next time you visit your local children’s museum, take time to slow down and watch your child learn. Then, join in!

Visit findachildrensmuseum.org/about for more information.

Researchers:

- Stephen Ashton, PhD, Thanksgiving Point
- Susan Foutz, The Children’s Museum of Indianapolis
- Cheryl McCallum, EdD, Children’s Museum of Houston
- Kimberly McKenney, Children’s Museum of Tacoma
- Nora Thompson, Port Discovery Children’s Museum
of operations, balancing equations, dividing resources). Veterinary clinic or farm exhibits can open conversations about animal behavior and traits, and medical clinic exhibits can prompt questions about the human body.

Light, magnetism, and air are examples of physical science content often found in children’s museums that can be explored through cause and effect. Understanding causal relationships leads to experimentation, creative use of materials, finding solutions, or making models.

Art studios and makerspaces provide interesting mediums for using STEM concepts and skills. Approaching art and STEM simultaneously, rather than as separate entities, creates additional entry points for learning. Capillary action is a great example of science content that can be authentically explored through art using primary colored markers, coffee filters, and water: a true STEAM activity.

Importantly, it is not necessary to be a scientist or engineer to develop good STEM programming at a children’s museum! It is far more important to be comfortable with the processes of STEM and confident in helping children and adults explore together. Exhibits and programming can be very simple: open-ended activities that promote trial-and-error experimentation work well in almost any setting. The best exhibits often have no right answer. Designing activities where children and adults can freely try alternatives and discuss the outcomes generates authentic co-learning moments.

**Lead by Example**

There are still many barriers to STEM learning for young children, whether it’s a lack of science identity among adult caregivers, persisting social biases (across gender, socioeconomic status, or race), or an increase in screen time leading to a decrease in outdoor play. Many community members have limited access to high quality STEM programming, which is why it is critical to embrace the work children’s museums already do to advance STEM and be thoughtful in how to make these experiences inclusive and accessible to all. Children’s museums already play an important role as conveners in their communities. They can also serve as resources for adults and children within networks of early learning organizations (preschools, libraries, Boys & Girls clubs, etc.). In doing, our field can pave the path for embracing STEM as a process and as a way of learning about the world.

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