4

Science Museums

Artificial curiosities in the early collections included a broad spectrum of practical and scientific technology—tools and utensils; locks and keys; lighting devices; clocks and watches; arms, armor, and apparatus of warfare; musical instruments; globes, astrolabes, and navigational devices; machines, automatons, engines, and mechanical models; telescopes, microscopes, and other optical apparatus; magnetic and electrical equipment; and scientific or philosophical apparatus and instruments devoted to mathematics, medicine, astronomy, chemistry, and physics. With the coming of the Industrial Revolution in the eighteenth century and the advent of the world's fairs in the nineteenth, increased recognition came to the products of humankind's inventive mind, and museums of technology and science arose. In contrast to natural history museums, science museums sought and exhibited collections relating to technology and the physical sciences.

Some of these museums evolved into science centers, with less emphasis on preserving collections for study and for future generations and more attention on educating the public about science and its principles. Melanie Quin outlines four forms of science centers: "scientists' workshop," "technological trade fair," "historical storehouse," and "adventure playground." She suggests that many centers are a combination of these forms.[1] Others suggest that the term *science center* is more appealing to potential visitors, as the word *museum* suggests stodgy halls with static collections while centers are seen as sites for activity and engagement.[2]

The discussion that follows addresses first those museums that have emerged from collections-based institutions, followed by those that originated as science centers, with the emphasis on interactive exhibitions rather than historical collections. Readers should be aware that both of these "types" of institutions are evolving and using techniques from both historical traditions, sometimes in the same galleries.[3]

European Collections of Artificial Curiosities

Medieval and Renaissance collectors usually owned abundant artificial curiosities. Jean de France, duc de Berry, had clocks, mechanisms, and scientific apparatus. Emperor Rudolph II brought to Prague great instrument makers such as Erasmus Habermel and Tycho Brahe, as well as the distinguished mathematician Johannes Kepler. Landgrave Wilhelm IV at Kassel collected instruments and studied mathematics and astronomy, while August I in Dresden used his collection to form a scientific research center in the famed Green Vaults of his palace.[4] Most of the seventeenth-century Italian scientific centers mentioned in chapter 3 had artificial as well as natural curiosities.[5]

Conservatoire National des Arts et Métiers

In the seventeenth century René Descartes suggested that the French government collect models of inventions for the instruction of artisans, but it was not until 1794 that the revolutionary

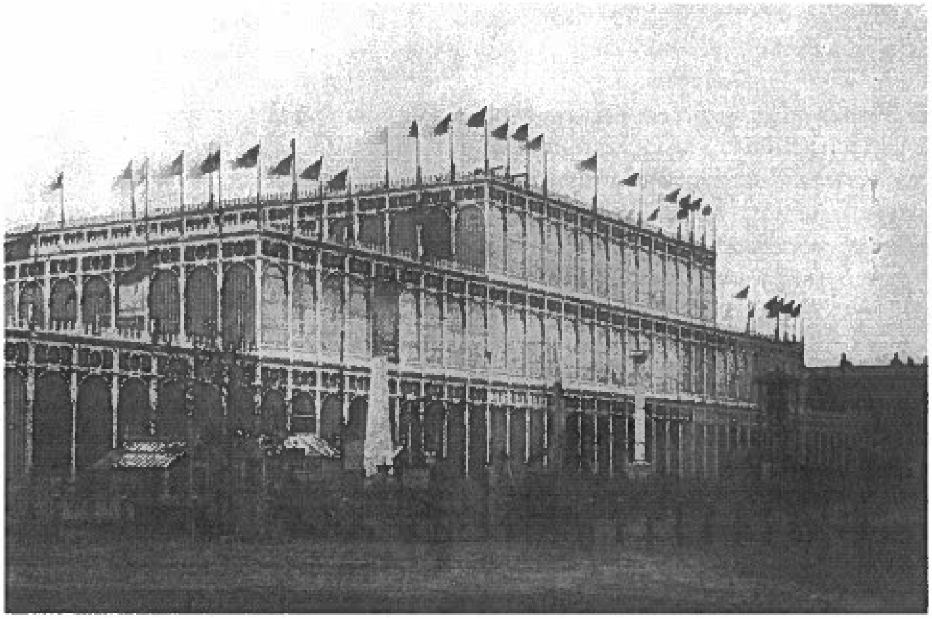
National Assembly established the Conservatoire National des Arts et Métiers (CNAM). This public depository of machines, inventions, models, tools, drawings, descriptions, and books on the applied arts and trades was housed in the buildings of the old Priory of Saint-Martin-des-Champs in Paris. The machines and models collected by the great engineer and inventor Jacques Vaucanson and by the Academie Royale des Sciences (1666) were the core of the collection that grew rapidly during the last half of the nineteenth century and received much material from the various universal exhibitions. The chief divisions of the collection were physics, electrical industries, geometry, weights and measures, mechanics and machines, transportation, chemical industries, mining and metallurgy, graphic arts, textile arts, arts of construction, and agriculture, and later industrial accident prevention and industrial hygiene. As early as 1819, the conservatoire hired professors to give courses on applying science to arts and industries that in one year in the 1860s enrolled 177,000 persons. About 1900, laboratories were established to test scientific apparatus, building materials, machines, and vegetable substances. The conservatoire also published a six-volume catalog of its holdings, between 1905 and 1910.

This educational emphasis remains today with CNAM providing courses for students whether enrolled in formal educational programs or simply adults—especially workers—interested in learning about technology. Some of the courses also allow for validation through experience (course credit for experiential work). In 2010, the Vaucanson School, a grand ecole for professionals who passed the baccalaureate, was founded.[6]

Resources include a central Paris museum and a library rich with materials relating to technology and industrial design. The modern museum, artfully fitted into the ancient Merovingian site, features early aircraft, including the first helicopter; automobiles; the origins of photography; motion pictures; radio and television; radar and the laser; and modern technology. It reports a collection of eighty thousand objects and 150,000 industrial designs. Its displays complement older rarities, such as the ornamental turning lathes that Peter the Great presented to the Académie des Sciences, materials on the evolution of the Jacquard loom, apparatus from Lavoisier's laboratory, and Daguerre's early equipment. For today's visitors to Paris, the Musée des Arts et Métiers offers the most traditional approach to displaying scientific and technological objects. That is not to say that there are not computer monitors and other up-to-date exhibition techniques in evidence. Of special interest is the program that brings working scientists into the galleries for the purpose of explaining their research work to visitors.

National Museum of Science and Industry, London

British manufacturers and businessmen were concerned to see that workingmen received practical technical education so as to produce more and better goods. Mechanics' institutes and government schools of design were established in the 1820s and 1830s, and sporadic trade exhibitions were held to show how art and science could be applied to industrial products. The Royal Society of Arts held several such exhibits, imitating those started in France. Henry Cole, versatile artist, musician, litterateur, and civil servant, became convinced that the society should sponsor an international exhibition so as to compare the industrial progress of many nations.[7] Prince Albert, consort of Queen Victoria and president of the society, eagerly embraced the idea, and his support was chiefly responsible for bringing into actuality the Great Exhibition of the Industry of All Nations at London in 1851. The "Crystal Palace" exhibition building—1,851 feet long and some 450 feet broad—enclosed eighteen acres that included several large trees. The exposition was an enormous success; in 120 days it attracted more than six million visitors. When it closed in October, unlike later world's fairs, it had a surplus—186,000 pounds. The exhibition had beneficial effects on British industrial design and international trade and inspired a series of world's fairs including the New York Crystal Palace (1853) and the Philadelphia Centennial Exhibition (1876). In addition, regional expositions



Claude-Marie Ferrier or Hugh Owen, view of west end of Crystal Palace, illustrated in *Reports by the Juries*, London, Spicer Brothers, 1852, v. 2 frontis.

Claude-Marie Ferrier or Hugh Owen, Crystal Palace, general view from transept, looking west, illustrated in *Reports by the Juries*, London, Spicer Brothers, 1852, v. 1, frontis.

showcasing art, design, and science were an important part of the exhibition imaginary.[8] Many of these expositions influenced the museum movement; their collections and, in some instances, their buildings were used to house museums.[9]

The royal commissioners, at the urging of Prince Albert, invested the earnings of the Great Exhibition in South Kensington real estate that adjoined the exposition site and eventually helped build a museum complex there. In 1857, the South Kensington Museum of Science and Art opened; it contained much material from the Crystal Palace. Bennet Woodcroft, patent commissioner, who gathered mechanical models in the Patent Office Museum, brought the collection to South Kensington. Woodcroft preserved important historic equipment, including a Necomen type of atmospheric engine (1791); the Boulton and Watt rotative beam engine (1788); Arkwright's cotton-spinning machine (1769); Symington's marine engine (1788); and the locomotives *Puffing Billy* (1813) and Stephenson's *Rocket* (1829). The collection eventually went to the South Kensington Museum. In 1909, when the building for the Victoria and Albert Museum was completed, the National Museum of Science and Industry (NMSI)—the Science Museum—became independent, opening in its own buildings across Exhibition Road in 1928. The Science Museum developed into one of the greatest museums of science and technology. It collected important historical material relating to power technology, transportation, communication, and manufacturing, creating large "taxonomic" collections of nineteenth-century industrial practices. In the 1960s the museum added important elements of biomedicine to its collecting roster.

Today, the museum offers lectures, demonstrations, films, and special exhibits that strive to tell the story of technological and medical achievement spanning centuries and the globe. As told by their mission, "We aim to inspire visitors with award-winning exhibitions, iconic objects and stories of incredible scientific achievement."[10] The museum has excellent children's programs, including a children's gallery that opened in 1931 with participatory exhibits and engaging programs, both onsite and online. Today's version of that gallery, the Launch Pad, offers children interactive programming both in the museum and through computer connections, at home or school. Children's programs, whether for kids with their parents or school classes, encompass thematic tours, special exhibition spaces, dramatic presentations within exhibitions, IMAX theater presentations, and even supervised sleepovers. These children's programs are especially significant, as they reflect current research into how young people learn. They balance current research and children's interests with historical artifacts relating to science and technology.[11]

The NMSI has expanded in the last thirty years. The museum consists of four entities outside of London as well: the National Railway Museum (York and Shildon); the Museum of Science and Industry (Manchester); and the National Media Museum (West Bradford, England). Of these, the Media Museum is of particular interest, as it crosses over between technology and science and creative media. Here are 3.5 million items of historical significance across the fields of photography, cinematography, and television. The Museum of Science and Industry offers exhibitions onsite and offsite experiments, such as summer 2016's *Pi: Platform for Investigation*, which brought science to the shopping center while offering platforms for conversations with Nobel Prize-winning scientists.[12] Finally, the Railway Museum offers three hundred years of history with more than one million objects. The site at Shildon opened in 2004 as a means of developing tourism in the town that was the birthplace of the modern railway. The museum also provides onsite access to archives and research through *Search Engine*, which enables visitors to view and see otherwise previously unseen artwork, papers, reports, photographs, and small objects.[13]

The Deutsches Museum, Munich

The French and British established the first technical museums, but the Germans devised an even more striking and influential one. Oskar von Miller, an outstanding engineer largely responsible for the Bavarian grid electrical system, was the founder of the Deutsches Museum von Meisterwerken der Naturwissenschaft und Technic (German Museum of Outstanding Achievements in Natural Science and Technology). As a young man in 1879, von Miller visited the conservatoire in Paris and the Patent Office Museum in South Kensington. In 1903, he presented a plan for a museum to illustrate the development of natural science and technology and the vivid influence of invention and mechanical progress on society.[14] It was endorsed enthusiastically by leading industrialists and scientists, engineering and scientific organizations, the National and Bavarian governments, and the city of Munich. The museum was housed for many years in an old building of the Bavarian National Museum and expanded into a disused infantry barracks. In 1903 the city gave it an island, formerly used as a coal dump, in the river Isar, where the kaiser observed the laying of the building's cornerstone in 1906. The city, Bavarian state, and German empire contributed millions of marks for construction. Industries furnished building materials free or at cost, organizations of workers donated labor, and the German railroads contributed transport; von Miller enjoyed his reputation as "the biggest highwayman and sturdiest beggar in Christendom." By 1913 the reinforced concrete structures were complete, but war delayed moving the collections, and the new museum island building did not open its 250,000 square feet of displays to the public until May 6, 1925, the seventieth birthday of its founder.

The Deutsches Museum introduced many innovations in its effort to make science and technology understandable for the general public. At the entrance was a Science Hall of Fame with likenesses of Germans such as Leibniz, Siemens, Krupp, and Kepler, as well as world scientists and inventors from Arkwright and Stephenson to Thomas Edison. Full-scale original or reproduced equipment was on display—for example, replicas of the *Puffing Billy* and *Rocket* locomotives in the Science Museum, the first Siemens electric locomotive (1899), early automobiles by Benz (1885) and Daimler (1886), and Edison's electric-lighting apparatus (1879). A museum visitor pushing buttons or turning cranks could animate many ingenious scale models. The principles of physics and chemistry were demonstrated, and a dramatic electrical surge generator (1.3 million volts) produced lightning flashes two meters long. The first Zeiss planetarium was installed, as well as realistic reconstructed mines for coal, iron, and salt with full-sized shafts, drifts, and galleries. The museum used period settings, such as an alchemist's laboratory and Galileo's study, as well as dioramas that included a glassblower's workshop and a high-tension power plant.

After extensive post-World War II reconstruction was completed in 1965, the Deutsches Museum retained the traditional chronological presentation of objects of historical interest but pioneered in offering ingenious and exciting exhibits and demonstrations of scientific laws of nature and their application through contemporary technology. It encouraged technological research with a fine scientific library of eight hundred thousand volumes, but its chief purpose was informal education for the masses. In terms of exhibition area, the number and importance of its objects and collections, and the breadth of its stated aims and the multiplicity of its activities, it is among the internationally leading scientific and technological museums. And its status is sure to increase after extensive renovations (through 2025) as part of the Future Initiative, which will modernize and transform the structure and exhibits even while remaining partially open.[15]

The influence of the Deutsches Museum has been pervasive and extensive. Its display techniques for modern technology emphasize how science works today, and many smaller technical museums have concentrated on this aspect, largely giving up the goal of exhibiting historical development. In the United States, the Smithsonian's Museum of History and Technology (later the Museum of American History); Chicago's Museum of Science and Industry; the Henry Ford in Dearborn, Michigan; and San Francisco's Exploratorium all trace their origins not only to the Deutsches Museum but also to its founder, Oskar von Miller. His interest in educating the public about science and technology within the museum setting continues to this day in these North American institutions. The Technical Museum of Vienna used materials accumulated during the International Exposition held there in 1873 and the 1908 Jubilee of Emperor Franz Joseph to build support for the museum. It was greatly influenced by the Deutsches Museum, and when it finally opened in 1918 it used many of von Miller's vivifying exhibition techniques. Its dynamic director, Ludwig Erhard, used consultants from most of Austria's trade organizations to build the museum's collections.[16]

Franklin Institute Science Museum, Philadelphia

Philadelphia's Franklin Institute, named to honor Benjamin Franklin, was founded in 1824 as a mechanics' institute to dispense information on the useful arts. Located in Independence Hall, it held important industrial exhibitions, awarded prizes, conducted classes and lectures, accumulated a library and a small technological museum with models and natural history specimens, and published a journal. In 1918, it began to develop laboratories, where scientists carried on chemical, biological, physics, and space research. The Franklin Institute opened its Fels Planetarium (only the second planetarium in the United States) in 1933 and a year later its Science Museum. In the Deutsches Museum tradition, the institute offered visitors interactive exhibitions. The institute's giant-sized, walk-through human heart complete with sound effects opened in 1953, providing visitors, especially young ones, an appreciation for the role of that organ in the health of us all. Today, the Franklin Institute Science Museum's exhibitions, including a recently refurbished planetarium with exhibitions relating to space and space exploration, focus on technology, science, and medicine, and, in the tradition of Benjamin Franklin, human inventiveness.[17]

International Electrical Exhibition, Franklin Institute, Philadelphia, published by Burk & McFetridge, 306 and 308 Chestnut Street, Philadelphia, 1884.

LIBRARY OF CONGRESS PRINTS AND PHOTOGRAPHS DIVISION, WASHINGTON, D.C. 20540 USA.

The Philadelphia Centennial and the Smithsonian Institution's Technology Museums

The Philadelphia Centennial Exposition of 1876 was a six-month extravaganza paying tribute to the hundredth anniversary of the Declaration of Independence. Five huge main buildings devoted to industrial exhibits, machinery, agriculture, horticulture, and art, together with 250 smaller structures, were scattered through 233 acres of the broad reaches of Fairmount Park. There were some thirty thousand exhibitors, including those from forty-one foreign governments. Machinery Hall was especially impressive with its great seven-ton Corliss engine started up by President Grant and Dom Pedro II, emperor of Brazil, and furnishing power to fourteen acres of clattering machinery that included printing presses, typecasting machines, envelope makers, and pin-forming machines amid huge Krupp cannons, car wheels, water pumps, boats, and locomotives. One enthusiastic reporter wrote, "Surely here, and not in literature, science, or art, is the true evidence of man's creative power; here is Prometheus Unbound." Federal, state, and city funds underwrote the cost of the fair to supplement concession fees and admission revenue from more than eight million visitors.[18]

Many foreign and state governments donated their centennial exhibits to the Smithsonian, and this flood of materials led to the erection of a National Museum Building (today the Arts and Industries Building) completed in 1881. The Smithsonian regents in 1924 appealed to Congress unsuccessfully for a "Museum of Engineering and Industry." At last, in 1955, Leonard Carmichael, the institution's seventh secretary, persuaded Congress to appropriate funds for a new National Museum of History and Technology that opened in 1964 (its name changed to the National Museum of American History in 1980). At the Museum of History and Technology, the chief science and technical displays included military ordnance, graphic arts, photography, musical instruments, farm machinery, road vehicles, American merchant shipping, bridges and tunnels, heavy machinery, electricity, tools, timekeepers, record players, typewriters, locks, physical sciences, medical sciences, manufactures, textiles, petroleum, nuclear energy, coal, iron, and steel. Full-scale original objects—including a railroad engine built into the building—meticulously built scale models, period rooms and shops, visitor-activated demonstrations, and motion pictures are used in interpreting these subjects.

This U.S. hybrid science and technology museum sought to address the gulf between history and technology, making manifest the American notion that technology is a "civilizing force" in the nation's development. The museum balances exhibitions of technology with historical topics, sometimes combining the two with temporary exhibitions such as *Science in American Life*. Today the museum's mission states that it "dedicates its collections and scholarship to inspiring a broader understanding of our nation and many peoples. We create learning opportunities; stimulate imaginations, and present challenging ideas about our country's past." Opened in 1994, the Lemelson Center for Invention and Innovation continues the museum's commitment to technology through its exhibitions, both in-house and traveling, and research and programs that meet its mission of "exploring invention and innovation through stories, activities, and research." Chief among these is the *Video Game Archive*, a recent initiative to record oral-history interviews with the first-generation inventors of the videogame industry.[19] Launched in 2008, Spark!Lab is an initiative to connect children from six to twelve years old to "collaborate, explore, test, experiment, and invent" with its national network that seeks to bring this kind of hands-on STEM-focused learning to the nation.[20]

National Air and Space Museum

Before the creation of the Smithsonian's Museum of History and Technology, the institution's Arts and Industries Building displayed the famed Wright Brother's *Flyer* (1903), Langley's *Aerodrome Six*, Charles Lindbergh's *Spirit of St. Louis*, Robert Goddard's first successful rocket, and numerous other examples of air and space equipment until the National Air and Space Museum on the National Mall was completed in 1976. Today, it houses many of the icons of flight, including those mentioned above as well as Chuck Yeager's *Bell X-1*, John Glenn's *Friendship 7* spacecraft, and the *Apollo 11* command module. In addition to this aeronautical and space hardware are materials that relate to man's centuries-old fascination with traveling in and through the air around us. There's even a "moon rock" for visitors to touch. On the National Mall visitors enjoy engaging permanent and temporary exhibitions, a children's gallery on flight, and an IMAX theater, along with a planetarium show. The museum's Center for Earth and Planetary Studies is the scientific research unit of the museum.

In addition to the site on the National Mall, the Air and Space Museum's Steven F. Udvar-Hazy Center in Chantilly, Virginia, near Washington Dulles International Airport, opened in December 2003. Its hangar-sized buildings permit the display of many more artifacts including a Lockheed SR-71 Blackbird, a Concorde, the Boeing B-29 *Enola Gay*, and the space shuttle *Discovery*. In addition to the artifacts on display, the center has an IMAX theater as well as an observation tower that yields 360-degree views of the nearby airport. In addition, the center serves as the site for preservation work—which can be observed by visitors. The museum has numerous online, onsite, and downloadable resources to enable parents and teachers to connect their children with the STEM learning and creativity afforded through science and space exploration.[21]

While the collections hold more than 44,000 aviation artifacts, 17,000-plus space-related artifacts, and 4,700-plus works of art, some are more notorious than others. In 2015, the museum launched a successful crowdfunding campaign on the platform Kickstarter to raise funds to conserve Neil Armstrong's *Apollo 11* spacesuit and Alan Shepard's *Mercury* spacesuit for exhibition. Called "Reboot the Suit," the campaign involved more than nine thousand contributors who, in the process of pledging funds, shared memories of this garment that enabled Armstrong to mission in 1969. Because the goal of $500,000 was reached within just five days, the museum employed the development officer's dream of tacking on a "stretch" goal by asking for an additional $200,000 for Shepherd's suit. Funds raised have been put toward conservation and have funded research and a custom-built mannequin and display for the show *Destination Moon* to open in 2020. On this first occasion of such a crowdfunding campaign, the Smithsonian underscored the power of objects to make connections with their audience while tapping into the potential of technologies and the web to reach unknown potential donors.[22]

The Museum of Science and Industry, Chicago

Julius Rosenwald, head of Sears, Roebuck and Company in Chicago, took his family to Munich in 1911 where he met the enthusiastic von Miller. Rosenwald continued visiting him through the years, and in 1921 he told the Chicago Commercial Club "that Chicago should have . . . a great Industrial Museum or Exhibition" with "machinery and working models illustrative of as many as possible of the mechanical processes of production and manufacture."[23] By 1926 the museum was incorporated, Rosenwald had given it $3 million, and the Chicago South Park Board had earmarked $3.5 million of a bond issue to renovate for its use the crumbling Palace of Fine Arts, a building left from the Columbian Exposition of 1893 and once used by the Field Museum of Natural History. In June 1933, during the Chicago centennial world's fair, "A Century of Progress," the museum managed to open partially, featuring a simulated coal mine complete with operating mine "cage elevator," shaft, mine train, and working face of a coal seam.

By 1940, the museum board elected as its president Lenox R. Lohr, who had successfully managed "A Century of Progress" and had since been serving as president of the National Broadcasting Company. Lohr combined the qualities of the hard-driving, tough businessman and the imaginative promoter. He did everything he could to build attendance, which in 1939 was about

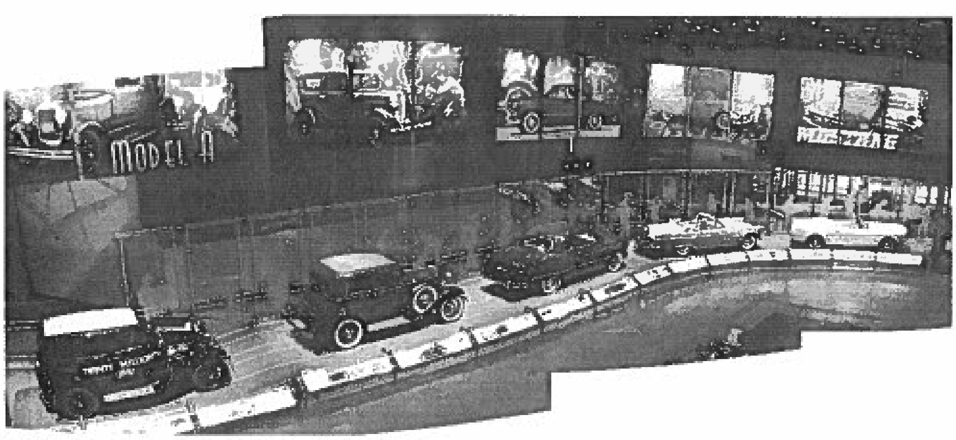
470,000; he believed that if it could reach a million, then more industry would be attracted to design and install significant technological displays. He thought 90 percent of the exhibits should be devoted to the present, only 10 percent to the past, and that 10 percent of the total should change each year. In exchange for a company's planning and erecting an exhibit, the museum would guarantee to show it for at least five years, would charge the company a fixed yearly fee that would reimburse the museum for operating, maintaining, and demonstrating it, and would give the company credit with an appropriate and discreet label. The museum would have full control of the exhibit to see that it met its standards of truthfulness, clarity, and educational purpose. This was, essentially, a world's-fair approach to the technical museum and required no curators but much imaginative showmanship and excellent public relations and promotion.

Today the museum boasts fourteen acres of inquiry, "400,000 square feet of hand-on exhibits designed to spark scientific inquiry and creativity."[24] Exhibits include *You! The Experience,* which examines the human body as well as the experiences, choices, personality, and environment through a thirteen-foot-tall, animated heart beating in real time! Other exhibits include a model railroad, a submarine, and a mineshaft in addition to examinations of sustainable futures.[25]

The Henry Ford, Dearborn, Michigan

At the start of the twentieth century, automobile industrialist Henry Ford began to accumulate vast stores of cultural and industrial Americana, including historic American buildings. He arranged his collections at Dearborn, Michigan, into two sections—an outdoor or open-air historical village similar to the Scandinavian folk museums, and an indoor museum extending behind a reproduction of Philadelphia's Independence Hall, Carpenter's Hall, and Old City Hall. Together these facilities, known as Greenfield Village, would show the story of progress through displays while the village would show use—two sides of the same coin as Ford wished to show "the history of our people as written into things their hands made and used," and he argued that "a piece of machinery, or anything that is made is like a book, if you can read it."

Construction on the first buildings at Greenfield Village began in 1928 and came to include craft and early machine shops, as well as the cycle shop of the Wright brothers, the re-creation of the New Jersey lab where Thomas Edison invented his electric lighting system, and birthplaces and buildings associated with ingenuity. Most important of all in showing technological development was the Mechanical Arts Hall, an eight-acre teakwood expanse with serried rows of machines and apparatus devoted to agriculture, domestic arts, lighting, power, machinery,



Ford Rouge Factory Tour, The Henry Ford, April 21, 2012.
FLICKR USER BARBARA ECKSTEIN, CC BY 2.0, HTTPS://WWW.FLICKR.COM/PHOTOS/BECKSTEI/7100807787/

communications, and transportation. All objects are full scale; most of them are original, but there are a few reproductions.

By the mid-1930s, the Village shops were staffed by people demonstrating traditional craft skills—including glassblowers, blacksmiths, and potters. Though Ford's museums contained many historical, architectural, and decorative arts materials, they were especially rich in important American and British items of industrial development. The twelve-acre museum contained a vast collection of largely uninterpreted artifacts that may have given the ordinary visitor visual and intellectual indigestion, but we are indebted to Ford for recognizing their value as historical evidence. Today, modern exhibition techniques have transformed the setting and its objects into comprehensible and valuable evidence of mainly British and American inventiveness. This section of the Henry Ford is most like a traditional science and technology museum, while the village area, with its blend of museum types, reflects history museum traditions and practices.[26]

Science Museum, Boston

Emerging from a nineteenth-century natural history society in Boston, the Museum of Science Boston, today takes its place as a leader in science museums. Following World War II, the museum's leaders expanded the scope of the "society" to encompass science and technology in addition to natural history. This change was made manifest when the museum relocated from Boston's Back Bay to the shores of the Charles River, forming a science park. Progress continued throughout the decades. With its 1951 expansion, the museum sought to address all the sciences within a single building. Subsequent additions—including an IMAX theater; the Charles Hayden Planetarium, the most technologically advanced digital theater in the region, which offers evening astronomy activities; a 4D theater that combines 3D features with extrasensory elements (such as weather effects) to give an immersive experience; flight simulators that afford 360 degrees of pitch; and the butterfly garden that enables observation of the four stages of the butterfly life cycle.[27]

Science Centers

Museums of science and technology emerged from the traditional enlightenment museum form, simply changing the exhibitions from those of natural objects to man-made phenomenon but continuing the overall purpose to aid visitors in understanding the world around us. Perhaps more than any other museum space, science centers hold particular importance, as they play a central role in the public understanding of science and offer engaging contexts for informal learning that are many times immersive and high tech, as well as hands on.

The earliest science centers opened their doors in the 1930s at the height of public appreciation for the contributions of science (and technology) to daily comforts. These centers, in many instances, emerged from international expositions where a nation's technological muscle was on display.

John Beetlestone et al. have traced the lineage of science museums across two lines: the grand museums, such as London's Science Museum and Deutsches Museum, Munich, and Chicago, and the hands-on approach developed in North America during the height of the space race. As Sheila Grinnell has noted, "In the late 1960s, after the decade of reform in science education that followed *Sputnik*'s launch in 1957, several institutions opened that elaborated on the concept of interactivity. The Exploratorium in San Francisco, and the Ontario Science Center near Toronto eschewed historical and industrial collections in favor of apparatus and programs designed to communicate basic science in terms readily accessible to visitors." The premise was that engagement through experience would serve to stimulate original thinking about science.[28]

Today, the range of exhibits include didactic and interactives, so-called "didacteractive," versus an enabling or empowering exhibit that may have multiple outcomes as a result of the high level of creative contribution.[29] With more than 1,400 science and technology centers worldwide, the range of opportunities and contexts is incredible, though a commonality is their focus on informal learning, as described by the Association of Science-Technology Centers. Founded in 1973, the ASTC is "a global organization providing collective voice, professional support, and programming opportunities for science centers, museums, and related institutions, whose innovative approaches to science learning inspire people of all ages about the wonders and meaning of science in their lives." With six hundred members in fifty countries, the organization's alliances and partnerships, publications, and professional development champion informal learning, the building block of the museum experience, by supporting the work of science centers, nature centers, museums, zoos, botanical gardens, and children's museums.[30]

Science and technology museums are inheritors of the extended subject area broadly known as STEM that includes engineering and math. Other extensions include STEAM, with the addition of art; SHTEAM, with the addition of history and art; and STREAM, with the addition of reading and art. While these fields have been around for a long time, their acronyms are a recent addition, and their presence (and even frequency of use) indicates that ways in which our environments indicate the value and strength of interdisciplinary learning. In fact, recent funding opportunities from the Institute for Museum and Library Services and the National Science Foundation pay heed to the connections between STEM learning and museums. The NSF, for instance, supports a number of museum exhibits, including *Race: Are We So Different?*—a traveling exhibition that looks at the science, history, and lived experience of race and racism in the United States—and a number of exhibits at specific institutions, including *CSI: The Experience*, an investigative and scientific principles-based crime scene mystery based at the Fort Worth Museum of Science and History, and *Skyline*, an interactive exhibition at the Chicago Children's Museum that enables visitors to design a skyscraper while learning STEAM. Projects such as these demonstrate how the successful integration of arts-based and interdisciplinary programs serves to recognize and value different approaches to learning in science-based disciplines.[31]

As varied as the exhibits within them, so are the names of these institutions, which do not necessarily mention science, technology, or even museum or center; they can be as innovative as the centers' collections and programming. Perhaps we might best think of these kinds of institutions in broadest terms and consider them STREAM (Science, Technology, Reading, Engineering, Arts, and Math) Centers rather than limiting them only to informal STEM learning.[32]

Ontario Science Centre, Canada

The Ontario Science Centre opened in Toronto in 1969 to celebrate Canada's centennial.[33] Housed in an architectural complex of three extremely innovative buildings, it has welcomed more than fifty million visitors since its opening. Though it has a few historical technological exhibits, its director declares its purpose is "to take science out of the laboratory and put it where casual browsers could observe and experience some of its challenge for themselves." The center, sometimes described as a push-button science adventure land, treats not only physical science and technology but also natural history, medicine, music, and the theater, and it operates an arboretum, an indoor rainforest exhibition, and an aquarium. With more than six hundred exhibits, it provides the largest museum-based education program in Canada, with more than forty curriculum-based school programs annually. In 2003 the Centre opened a "Kidspark" for children under eight years old that proved so popular that it doubled in size by 2005. Under the principle of "Agents of Change," the Centre completed a renovation in 2007 that revitalized a third of the public spaces and brought into focus an entirely experimental family innovation center. In 2015, the Nature Escape, four acres of outdoor space, opened, as did the temporary exhibit *To Be an Astronaut*, which traces Canadian space history and its importance to STEM education. Other exhibitions have focused on the human body and the magical world of Hogwarts in *Harry Potter: The Exhibition*, thus heeding the connections between spectacle and science.[34]

Exploratorium, San Francisco

Oskar von Miller of Munich's Deutsches Museum personally influenced founders of other science and technology museums (as mentioned here, Henry Ford and Julius Rosenwald) and, more recently, physicist Frank Oppenheimer, creator and founder of the Exploratorium in San Francisco. From his position as a professor at the University of Colorado, Oppenheimer envisioned a new sort of museum that addressed the interests of learners and their curiosity about the world around them. He called it a Museum of Science, Art, Industry and Craft (MOSAIC)—generically, "an exploratorium," a place where visitors could understand the world by exploring it themselves. Oppenheimer acknowledged that a visit to the Deutsches Museum sparked his thinking about how museums could "teach" their visitors.

In 1968 the Exploratorium opened in the abandoned buildings of the Pan-American Exposition in San Francisco.[35] The early exhibitions were "works in progress" that captured the imagination of the few visitors that found their way to the door. Youthful explainers within the exhibit spaces offered explanations and guidance to visitors when asked. Oppenheimer explained the Exploratorium's purpose: "It should be a place where people come both to teach and to learn."[36] Today, the Exploratorium and Oppenheimer's vision of the dynamic role museums can play in engaging their visitors are models for other institutions worldwide. The Exploratorium pronounces its broadest service by stating that it "create[s] tools and experiences that help you to become an active explorer: hundreds of explore-for-yourself exhibits, a website with over 50,000 pages of content, film screenings, evening art and science events for adults, plus much more. We also

Exploratorium at Pier 15, San Francisco, March 20, 2013.
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create professional development programs for educators, and are at the forefront of changing the way science is taught. We share our exhibits and expertise with museums worldwide." Truly, the onsite and online as well as takeaways are critical to the Exploratorium's practice.[37]

Onsite, the center offers six main galleries with interactive exhibits alongside an observation area called *Exhibit Workshop* where visitors can look at exhibits in the making.[38] The museum also offers teaching and learning tools that provide museum professionals across the world with simple ways to illustrate scientific principles, whether in community-based children's museums or larger regional science centers. The resources include the websites (and microsites within the Exploratorium's main site); a learning commons for educators alongside a digital library of pdfs, movies, podcasts, and other media; publications focusing on formative evaluation, arts integration, and more focused topics; downloadable apps that can be used as teaching tools; and descriptions and instructions on how to build mini-versions (a.k.a. "snacks") of Exploratorium exhibits.[39] In addition, the Exploratorium is seen as the prototype for more than one thousand hands-on, participatory institutions worldwide.[40]

Teknorama, Heureka, and Experimentarium

Past president of the ASTC and former president of the Museum of Science and Industry in Chicago, Victor J. Danilov suggests that science centers have become popular institutions in American cities of medium size; for example, in Columbus, Ohio (Center of Science and Industry), and Baltimore, Maryland (Maryland Science Center). Quality centers can also be found in smaller cities, such the Bradbury Science Museum in Los Alamos, New Mexico (population just over twelve thousand!), where more than forty interactive exhibits document the history of the research and development of nuclear weapons (an operation during World War II that came to be known as the Manhattan Project) while also looking at broader political, social, economic, and environmental concerns.[41]

The notion of a science center fit for a smaller community—as opposed to megaliths—applies to European cities, especially in Scandinavia. Three warrant special attention for their innovations and contributions to the changing nature of science centers as a class of museum organizations. The privately financed Tekniska Museet (Swedish National Museum of Science and Technology) of Stockholm opened in 1936, and followed Deutsches Museum practices. It was recently named "Museum of the Year" in 2016 by the Association of Swedish Museums and ICOM Sweden. With government support, its goal is to use its collections and knowledge about industrial society, technology, and technological development to engage and satisfy people's interest and to generate a belief in the future. The galleries are designed especially to engage children with the world around them and, like many science centers, they have more recently broadened their reach to encourage engagement and learning across all age groups. Examples of compelling exhibits include *100 Innovations*, which looks at the most important inventions in history, as voted by Swedish students and affirmed by online and onsite visitors who can also cast a vote based upon the museum display.[42] *Teknoleket* is an interactive exhibit geared toward younger children with activities and experiments to show mechanics as well as aspects of natural history and technology.

In Finland in 1984, the Finnish Science Center Foundation brought together academics, scientists, government officials, and trade unions to create a center that would display and demonstrate achievements in science and technology. The foundation selected the city of Vantaa, north of Helsinki, as the site for the new center. The city invested in establishing the center as a part of its effort to attract tourists. In 1989 Heureka opened to the public with two hundred interactive exhibitions, programming for schoolchildren, and traveling exhibitions. It seeks to reach audiences of all ages, as noted by the tagline, "The joy of discovery and fun experiences for all ages!" The site boasts a planetarium, outdoor exhibitions including the wheelchair track that enables visitors to negotiate movement, and the Basketball Rat Stadium. Begun in 1995 as a copycat idea from Columbus's Center for Science and Industry, this sport exhibit demonstrates concepts of behavior modification as well as stimulus-reaction while engaging audiences in the unlikeliest of games.[43] The museum also travels its exhibitions in the form of *Science Circus*, which involves a thirty-minute show and themed exhibits about electricity, chemical reactions, biology, physiology, and psychology.[44]

To the south in Denmark, the Center for Information about Natural Science and Modern Technology began, in 1986, as a study of "[a national] institution of learning where concrete experience was in the fore." For nearly five years, traveling pilot exhibits attracted visitors to this approach to learning. In 1991, the center opened to the public under the name Experimentarium in Tuborg's abandoned bottling plant, just north of Copenhagen. Currently undergoing renovation and expansion, the exhibitions will reopen in 2017 after welcoming visitors for two and a half years at a temporary site, called Experimentarium City, which was located more centrally in Christianshavn. With exhibits focusing on science, technology, the environment, and health, the center described its purpose this way: "Danish science has been given a new window to the world as well as a new channel of communication. The center was to be a bridge between experts and lay people."[45]

Challenges and Opportunities

Who Defines Progress?

Industrialization and the machine have, of course, brought much progress; a large portion of humankind no longer works from sunup to sundown to obtain the bare necessities of life. There can be no doubt that most museums of science and technology glorify machines. But industrialization also creates problems—harm to the environment and ecology; neglect of social, cultural, and humanistic values; depletion of resources; and even threats of human extinction. Science and technology museums often have been "partners" with industry (and even government agencies).

A critical glance has been aimed toward science centers, however. Kenneth Hudson, in his book *Museums of Influence*, closes his chapter on science, technology, and industry museums with this admonition: "In today's world, a museum of science and technology which does not encourage its visitors to think of the human and social consequences of new developments is acting in a singularly irresponsible and out-of-date fashion. To worship Progress uncritically may suit the manufacturers and advertisers but it is not in the best interests of humanity."[46] And yet it is clear from the overview of these museums and the sampling of exhibitions featured in this chapter alone that STEM-focused museums and centers are taking on environmental advocacy.

Scientific "Literacy"

How do science museums address the gap between rapidly changing science and a diverse public audience with little knowledge of basic scientific principles? Where should interpretation begin in this process, and how can the museum or science center balance engaging visitors with conveying scientific concepts? These questions are especially challenging for the science center with its reputation for "hands-on" activities that are comprehensible to visitors of all ages and interests.

Those science centers that evolved from older institutions emerged from two museum branches: natural history (i.e., Boston) and technology (i.e., Chicago and London). Today's centers have expanded to include STEM as well as health, psychology, and related fields. Admonishing the dwindling aspect of science in such institutions, British science writer Graham

Farmelo argues, "[S]cience centers do scant justice to basic science and . . . the overwhelming majority of them concentrate on topics that are most amenable to public presentation—notably, applied physics and technology. It is possible to argue that the term 'science centers' is really a misnomer—perhaps they should have been called 'technology centers'?"[47] It seems that these institutions—regardless of what we call them—offer welcome learning environments and direct engagement with collections and interactives, often with the assistance and guide of a facilitator or explainer. The Oppenheimer method has taken hold and has ushered in an entirely new expectation of museum staff that calls for directed guidance as well as free-choice learning.[48]

Science as Public Activity

With the demands of ever-increasing attendance, how do science centers satisfy visitors who have come to see "science in action" when scientific processes rarely engage spectators? As educator Melanie Quin writes, "Science is a slow, often tedious, business, with most experiments being controls designed to show that in certain conditions nothing happens. . . . Is it simply that science museums seldom attempt explanations because explaining is not their traditional aim? Or have they found it impossible to present ideas in a museum context? Are the concepts and principles underlying appearances just too hard to present without the kind of background knowledge instilled over years, in courses in schools and universities? We may need somewhat separated, more thoughtful 'Explanatories.'"[49]

Factoring in the mode of access to science centers (and other museums, too), consider that the Exploratorium launched its website in 1993—truly early on in the post-Internet revolution. In thinking of the connections between the web and science centers, in 2001 Rob Semper wrote of the Internet as a valuable extension of a science center's visitor's "browsing" behavior. He reported that science centers were using their websites for connecting with audiences and to support membership, admissions, public information, and exhibition promotion. He described the Exploratorium as becoming a "giant production studio for the web." In contrast, in 2006, Jim Spadaccini explained how those Exploratorium beginnings remained unfulfilled. He suggested that the museums must "embrace user-created content . . . the science center 'audience' could be seen as potential collaborators and, in some cases, even content experts." Spadaccini's claim meant the need to embrace two-way communications through the web, which challenges the museums "as authoritative sources of information."[50]

This notion of a public activity and browseability is taken further through the citizen scientist (a.k.a. #citsci and Science 2.0) movement. To be fair, the notion of contributing scientists as individuals who actually made their living doing something else is actually quite old, as is the notion of collaboration and networking (even in a presocial media world). The newish movement, accelerated through the Internet and social media, enables the public to gather useful data for researchers—as in counting or identifying bees, birds, and fish in one's region—while also giving citizens—in the form of schoolchildren and adults—the ability to contribute to something greater. For example, eBird, launched by the Cornell Lab of Ornithology as an Internet-based citizen science project, enabled birders to report sightings and observations. Other examples of human computation exercises include FoldIt, which helps predict protein structures, and GalaxyZoo, which identifies galaxies out of celestial images.[51] A website offers listings of more than 1,600 formal and informal research projects and events that include agriculture, astronomy, climate, geography, nature, and more. This move toward anchoring science learning in the everyday while contributing to a collective endeavor is a return to Joseph Henry's gathering of meteorological data that, in the case of the new work, impacts scientific research, particularly in the fields of biology, conservation, and ecology that have been the primary fields utilizing citizen science.[52]

Notes

1. Melanie Quin, "Aims, Strengths, and Weaknesses of the European Science Centre Movement," in *Towards the Museum of the Future: New European Perspectives*, eds. Roger Miles and Lauro Zavala (London: Routledge, 1994), 40.
2. Victor Danilov, *America's Science Museums* (New York: Greenwood Press, 1990), 291; Howard Learner, *White Paper on Science Museums* (Washington, DC: Center for Science in the Public Interest, 1979); Victor J. Danilov, *Science and Technology Centers* (Cambridge, MA: MIT Press, 1982).
3. John G. Beetlestone, Colin H. Johnson, Melanie Quin, and Harry White, "The Science Center Movement: Contexts, Practice, New Challenges," *Public Understanding of Science* 7, no. 1 (January 1998): 5-26; Kenneth Hudson, *Museums of Influence* (Cambridge: Cambridge University Press, 1987), 88-112.
4. Silvio A. Bedini, "The Evolution of Science Museums," *Technology and Culture* 6, no. 1 (Winter 1965): 1-29, especially the table on pages 2-6; Germain Bazin, *The Museum Age* (New York: Universe Books, 1967), 37-39, 75-76, 86-87, 144.
5. For instance, Aldrovandi, Cospi, and Marsigli at Bologna; the Medici brothers, Grand Duke Ferdinand II and Leopold, with their Academia del Cimento (of the Experiment) in Florence; Ludovico and Manfredo Settala, father and son, in Milan; and the Jesuit Kircher in Rome. Martha Ornstein Bronfenbrenner, *The Role of Scientific Societies in the Seventeenth Century*, 3rd ed. (Chicago: University of Chicago Press, 1938), 77-90, 219. So did Ole Worm and Christian V in Denmark and the Tradescants and the Royal Society (1662) in London. The Society for the Encouragement of Arts, Manufactures, and Commerce (now the Royal Society of Arts), founded in 1754, eventually placed its collection of models in the Science Museum. The Teyler Stichting (Foundation) established at Haarlem in 1778 had the chemist and electrical experimenter Martin van Marum as its first director and still contains his great electrostatic machine of 1784. See Bedini, "The Evolution," 18-20; Ornstein Bronfenbrenner, *The Role*, 112-15; Eugene S. Ferguson, "Technical Museums and International Exhibitions," *Technology and Culture* 6 (1965): 30-46, especially 32, 45; Bazin, *The Museum Age*, 144-45.
6. CNAM, "Key Dates," http://www.cnam.eu/.
7. Edward P. Alexander, "Henry Cole and the South Kensington Museum," *Museum Masters: Their Museums and Their Influence* (Nashville: American Association of State and Local History, 1983), 141-75.
8. For instance, the Southern Exposition was an annual event held from 1883 to 1887 in Louisville. See "Louisville's Southern Exposition," *The Filson Historical Society*, http://filsonhistorical.org/galleries/louisvilles-southern-exposition/.
9. Kenneth W. Luckhurst, *The Story of Exhibitions* (New York: Studio Publications, 1951), 83-116; Christopher Hobhouse, *1851 and the Crystal Palace*, New York, 1937, 1-9, 24-40, 43-61, 150-65; Hector Bolitho, *Albert, Prince Consort* (Indianapolis: Bobbs-Merrill, 1964), 117, 119-20, 125-28; Ferguson, "Technical Museums," 30, 32-33, 35-39; Lord Amulree, "The Museum as an Aid to the Encouragement of Arts, Manufactures, and Commerce," *Museums Journal* 39 (November 1939): 350-56; Kenneth Hudson, *A Social History of Museums: What the Visitors Thought* (Atlantic Highlands, NJ: Humanities Press, 1975), 41-47.
10. Science Museum, "About Us," http://www.sciencemuseum.org.uk/about-us.
11. Science Museum, "About Us," http://www.sciencemuseum.org.uk/about-us.
12. In September 2016, the center hosted Professor Andre Geim to discuss materials with extraordinary properties. See http://msimanchester.org.uk/whats-on/activity/in-conversation-professor-andre-geim.
13. On the history of the Railway Museum and its two locations, see http://www.nrm.org.uk/aboutus/history.

14. Alexander, "Oskar von Miller and the Deutsches Museum," in *Museum Masters*, 341-75.
15. Charles R. Richards, *The Industrial Museum* (New York: Macmillan, 1925), 20-32, 70-110; Ferguson, "Technical Museums," 30, 41-42; Karl Bassler, "Deutsches Museum: Museum of Science and Technology," *Museum* 2 (1949): 171-79; "Heavy Current Electrotechnology: A New Department of the Deutsches Museum," *Museum* 7 (1954): 161-66; three articles by Hermann Auer: "The Deutsches Museum, Munich," *Museum* 20 (1967): 199-201; "Problems of Science and Technology Museums: The Experience of the Deutsches Museum, Munich," *Museum* 21 (1968): 128-39; and "Museums of the Natural and Exact Sciences," *Museum* 26 (1974): 68-75. See also "Oskar von Miller," *Museums Journal* 34 (June 1934): 76-79; Richards, *Industrial Museum*, 33-45, 111; Gunter Knerr, "Technology Museums: New Publics, New Partners," *Museum International* 288, no. 4 (October-December 2000): 8-13; http://www.deutsches-museum.de.
16. "Technisches Museum fur Industrie und Gwerbe, Wien," *Museum* 5 (1952): 98; http://www.tmw.at.
17. Bruce Sinclair, *Philadelphia's Philosopher Mechanics: A History of the Franklin Institute, 1824-1865* (Baltimore: Johns Hopkins University Press, 1974), 39-41, 93-96, 100-103, 259-61; I. M. Levitt, "The Science Teaching Museum of the Franklin Institute, Philadelphia," *Museum* 20 (1967): 169-71; Robert W. Neatherby, "Education and the Franklin Institute Science Museum," *Museums Journal* 64 (June 1964): 50-58; Ferguson, "Technical Museums," 34-35; Brooke Hindle, "Museum Treatment of Industrialization: History, Problems, Opportunities," *Curator* 15 (1972): 216; Victor J. Danilov, "Under the Microscope," *Museum News* 52 (March 1974): 37-38; *International Committee, Museums of Science and Technology, Guidebook*, 1974, 145-54; http://www.fi.edu.
18. Charles S. Keyser, *Fairmount Park and the International Exhibition at Philadelphia* (Philadelphia: Claxton, Remsen & Haffelfinger, 1876), 1-82; Lynne Vincent Cheney, "1876: The Eagle Screams," *American Heritage* 25 (April 1974): 15-35, 98-99; Luckhurst, *Story of Exhibitions*, 52, 124-25, 136-37, 175, 190, 202, 206; Paul H. Oehser, *The Smithsonian Institution* (New York: Prager, 1970), 49-57, 189-90, 193-94, 196-97; Geoffrey T. Hellman, *The Smithsonian Institution: Octopus on the Mall* (Philadelphia: Lippincott, 1967), 97-98; Walter Karp, *The Smithsonian Institution: An Establishment for the Increase and Diffusion of Knowledge among Men* (Washington, DC: Smithsonian Institution, 1965), 55-69, 75-93; Gene Gurney, *The Smithsonian Institution: A Picture Story of Its Buildings, Exhibits and Activities* (New York: Crown, 1964), 7-22, 62-97, 99-102; *National Museum of History and Technology, Exhibits in the Museum of History and Technology: An Illustrated Tour* (Washington, DC: Smithsonian Institution, 1968), 40-41, 45-51, 60-63, 74-127; W. T. O'Dea and L. A. West, "Editorial: Museums of Science and Industry," *Museum* 20 (1967): 150-57, 190-93; Frank A. Taylor, "The Museums of Science and Technology in the United States," *Museum* 20 (1967): 158-63; *Museums Journal* 27 (April 1927): 327; *Museums Journal* 28 (December 1928): 204; *Museums Journal* 48 (November 1948): 174; Robert P. Multhauf, "A Museum Case History: The Department of Science and Technology of the United States Museum of History and Technology," *Technology and Culture* 6 (Winter 1965): 47-58; Bernard S. Finn, "The Science Museum Today," *Technology and Culture* 6 (Winter 1965): 74-82. One centennial park visitor was Dom Pedro II, last emperor of Brazil. He loved museums, technology, and education. He was a collector and spent a good deal of time at the Smithsonian.
19. Arthur P. Molella, "Tilting at Windmills," *Technology and Culture* 36, no. 4 (1995): 1000-1006; Arthur P. Molella, "The Museum That Might Have Been: The Smithsonian's National Museum of Engineering and Industry," *Technology and Culture* 32, no. 2 (1991): 237-63; http://americanhistory.si.edu/. For the Lemelson, see http://invention.si.edu/.
20. For Spark!Lab, see http://invention.si.edu/about-sparklab.

21. Michal McMahon, "The Romance of Technological Progress: A Critical Review of the National Air and Space Museum," *Technology and Culture* 22, no. 2 (1981): 281-96; Michael Wallace, *Mickey Mouse History and Other Essays on American Memory* (Philadelphia: Temple University Press, 1996), 288-91; see http://airandspace.si.edu and https://airandspace.si.edu/visit/educators.
22. Marina Koren, "The Smithsonian Raises $700,000 on Kickstarter to Save Neil Armstrong's Spacesuit," *The Atlantic*, August 18, 2015, http://www.theatlantic.com/technology/archive/2015/08/smithsonian-neil-armstrong-spacesuit-museum/401663/.
23. Herman Kogan, *A Continuing Marvel: The Story of the Museum of Science and Industry* (Garden City, NY: Doubleday, 1973), 9-11, 18-19, 30, 43, 45-55, 71, 87, 89, 95, 98-101, 111-13, 115, 117-20, 124-29, 131-33, 134, 138-43, 145-57, 162-63, 174, 185, 194-95, 197-99, 205.
24. Museum of Science and Industry, Chicago, "About the Museum," http://www.msichicago.org/explore/about-us/about-the-museum/.
25. Lenox Riley Lohr, "Publicity and Public Relations," *Museum* 4 (1951): 229-33; Daniel M. MacMaster, "The Museum of Science and Industry, Chicago," *Museum* 20 (1967): 167-68; Hindle, "Museum Treatment," 206-19; Ferguson, "Technical Museums," 42-46; Danilov, "Under the Microscope," 37-44; *International Committee, Museums of Science and Technology, Guidebook*, 1974, 169-76; and the museum's exhibit sites, including http://www.msichicago.org/visit/plan-your-visit/ and http://www.msichicago.org/explore/whats-here/exhibits/you-the-experience/.
26. Henry Ford Museum Staff, *Greenfield Village and Henry Ford Museum* (New York: Crown Publishers, 1972), 6-25, 46, 50-53, 70-91, 98-103, 142-217; *Greenfield Village and Henry Ford Museum, Selected Treasures* (Dearborn: Edison Institute, 1969), 4, 6; William Greenleaf, *From These Beginnings: The Early Philanthropies of Henry and Edsel Ford, 1911-1936* (Detroit: Wayne State University Press, 1964), 71-112; Allan Nevins and Frank Ernest Hill, *Ford: Expansion and Challenge, 1915-1933* (New York: Charles Scribner's Sons, 1957), 497, 500-506; Ferguson, "Technical Museums," 42; Hindle, "Museum Treatment," 210-11; https://www.thehenryford.org/history-and-mission/creating-our-campus/.
27. Museum of Science, http://www.mos.org/.
28. Sheila Grinnell, *A New Place for Learning Science: Starting and Running a Science Center* (Washington, DC: Associate of Science-Technology Centers, 1992), 6-7.
29. Beetlestone et al., "The Science Center Movement," 7-8.
30. ASTC, "About ASTC," http://www.astc.org/.
31. National Science Foundation, "Now Showing: Film, TV, Museums, and More," https://www.nsf.gov/news/now_showing/museums/skyline.jsp.
32. Archie F. Key, *Beyond Four Walls: The Origins and Development of Canadian Museums* (Toronto, 1974), 263-65; Archie F. Key, "Canada's Museum Explosion," *Museums Journal* 67 (June 1967): 26-27; O'Dea and West, "Editorial," 150-57; *International Committee, Museums of Science and Technology, Guidebook*, 1974, 121-28; Beetlestone et al., "The Science Center Movement," 10; Sheila Grinnell, *A New Place for Learning Science: Starting Science Centers and Keeping Them Running* (Washington, DC: Associate of Science-Technology Centers, 1992); Alice Carnes, "Showplace, Playground or Forum? Choice Point for Science Museums," *Museum News* 64, no. 4 (April 1986): 29-35; G. Farmelo and J. Carding, *Here and Now: Contemporary Science and Technology in Museums and Science Centers*, 1996; Proceedings, Science Museum, London; Per-Edvin Persson, "The Changing Science Center: Sustaining Our Mission into the 21st Century," *ASTC Dimensions* (January-February 2000), 3-6.
33. Canada's centennial was held in 1967 in celebration of the Canadian Confederation.
34. Douglas N. Ormand, "The Ontario Science Centre, Toronto," *Museum* 26, no. 2 (1974): 76-85; Susan M. Pearce, ed., *Exploring Science in America* (London: Athlone, 1996); Beetlestone et al.,

"The Science Center Movement," 5–26; Ronen Mir, "Natural Attractions: Implementing Your Science Park," *ASTC Dimensions* (March–April 2001), 3–5; Statistics from Ontario Science Center, "Backgrounder," http://www.ontariosciencecentre.ca/WhoWeAre/Backgrounder/. The Harry Potter exhibit was organized by Branded Entertainment/Exhibitgroup/Giltspur and traveled to Boston and Chicago as well.

35. The Exploratorium moved from the Palace of Fine Arts to Pier 15 on the waterfront of the Embarcadero. Construction began on the new site in 2010, and the museum held its grand opening at the new location in 2013. See http://www.exploratorium.edu/piers/.
36. Frank Oppenheimer, "A Rationale for a Science Museum," *Curator* 11, no. 3 (1968): 206.
37. Exploratorium, http://www.exploratorium.edu/about-us.
38. Exploratorium, "Designing Teaching and Leaning Tools," http://www.exploratorium.edu/education/designing-teaching-learning-tools.
39. Edward P. Alexander, "Frank Friedman Oppenheimer," in *The Museum in America: Innovators and Pioneers* (Walnut Creek, CA: AltaMira Press, 1997), 117–32; Hilde S. Hein, *The Exploratorium: The Museum as Laboratory* (Washington, DC: Smithsonian Press, 1990); Sally Deunsing, "Exporting the Exploratorium: Creating a Culture of Learning," *ASTC Dimensions* (November–December 1999), 3–7; Linda Dackman, "Invisible Aesthetic: A Somewhat Humorous, Slightly Profound Interview with Frank Oppenheimer," *Museum* 150 (1986): 120–22.
40. This trajectory is communicated in the website sharing the new beginning for the museum as part of its construction and move in 2013. See http://www.exploratorium.edu/piers/.
41. Bradbury Science Museum, "About the Museum," http://www.lanl.gov/museum/visit/about-museum.php.
42. *100 Innovations* is on view from 2012 to 2017 at Tekniska Museet. See http://www.tekniskamuseet.se/1/2672.html and http://www.100innovationer.com/.
43. Heureka, "About Heureka," http://www.heureka.fi/en/about-heureka.
44. Heureka, "Science Circus," http://www.heureka.fi/en/science-circus.
45. H. Philip Spratt, "Tekniska Museet: A New Science Museum Opened in Stockholm," *Museums Journal* 36 (September 1936): 243–45; "The Technical Museum, Stockholm," *Museums Journal* 45 (April 1945): 4–6; Thorsten Althin, "The Automarium of the Tekniska Museum, Stockholm," *Museum* 7 (1954): 167–73; S. Strandh, "The Museum of Science and Technology, Stockholm," *Museum* 20 (1967): 188–90; International Committee, *Museums of Science and Technology Guidebook*, 1974, 81–104, 253–76; http://www.experimentarium.dk; http://www.tekniskamuseet.se; http://www.heureka.fi; Experimentarium, Homepage, https://en.experimentarium.dk/.
46. Kenneth Hudson, *Museums of Influence* (Cambridge: Cambridge University Press, 1987), 112.
47. Beetlestone et al., "The Science Center Movement," 24.
48. Sue Allen, "Designs for Learning: Studying Science Museum Exhibits That Do More Than Entertain," *Science Education. Supplement: In Principle, In Practice: Perspectives on a Decade of Museum Learning Research*, 2003, S17–33.
49. Melanie Quin, "The European Science Centre Movement," in *Towards the Museum of the Future*, 47.
50. Rob Semper, "Nodes and Connections: Science Museums in the Networked Age," *ASTC Dimensions* (November–December 2001); Jim Spadaccini, "Museum and the New Web: The Promise of Social Technologies," *ASTC Dimensions* (July–August 2006); Leo Tan and R. Subramaniam, *E-Learning and Virtual Science Centers* (Hershey, PA: Information Science Publishing, 2004). To return to the notion of "browsing" behavior, these two authors suggest that science centers especially need to approach the web as they do their onsite exhibition spaces and programming; simply stated, it is merely browsing in a different venue.

51. C. Wood, B. Sullivan, M. Iliff, D. Fink, and S. Kelling, "eBird: Engaging Birders in Science and Conservation." *PLoS Biology* 9, no. 12:e1001220; http://ebird.org/content/ebird/news/rba; http://fold.it/portal/info/science.
52. The listing of citsci projects is here: http://scistarter.com/about.html. Citing Follet and Strezov's study that reports that the first article published using citizen science appeared in 1997. In 2007, six papers were presented at the Ecological Society of America meeting. And since this time, peer-reviewed citizen science articles have increased. See Ria Follett et al., "An Analysis of Citizen Science Based Research: Usage and Publication Patterns," *PLOS (Public Library of Science) ONE* (2015), doi:10.1371/journal.pone.0143687; Christopher Kullenberg et al., "What Is Citizen Science? A Scientometric Meta-Analysis," *PLOS (Public Library of Science) ONE* (2016), doi: 10.1371/journal.pone.0147152; both of which were cited in Jennifer Grigg, "Examining New Trends in Citizen Science," Phys.org, February 2, 2016, http://phys.org/news/2016-02-trends-citizen-science.html.