

# From Awe to Experience, from Artefacts to Edufacts? On the Post-War Revolution in the Objects of Science Communication

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**Abstract.** The central message of my presentation is that in the 20th century, there was a revolution in the way science was presented. It became most visible in a significant change in the kinds of objects used to explain science to a wider public. For centuries, the objects came from the academy, university, laboratory or industry. Either directly as artefacts or as modifications and simplifications that might work better in lectures and demonstrations, they inhabited the display cases in schools, universities, science collections and museums. It was not until the 1960s in North America that science museums – or rather science centres, as they soon became known – began to build their own exhibits in such a way as to present scientific phenomena as vividly as possible. How did this turn from artefacts to ‘edufacts’ come about and what implications did it have?

## 1. Introduction: From A to E

In the title of my talk, I have characterised this revolution as a change from A to E. From Awe to Experience, this is the change in the ways of public engagement with scientific objects and phenomena, from silent admiration or even veneration of scientific masterpieces and technical wonders to hands-on, interactive and immersive experiences of scientific phenomena and technological gadgets. And from Artefacts to Edufacts, this is the change in the objects involved in science communication. While museums need the original, the authentic, the firsts and the best, and consequently, the glass case, the railings and the alarm system, the science centre can easily replace a broken exhibit by rebuilding it in its workshop. Or – especially today – by simply ordering it on the Internet. It is out of the question that a historical artefact could somehow be improved or modified. Custom-made Edufacts, however, are constantly being updated and altered, especially if they do not work with visitors as intended.

And for the case of the United States of America, one can add another change from A to E. From the Attic of the Nation (which was the nickname of the Smithsonian Institution in Washington, whose Arts and Industry Building was so cramped with artefacts from science and technology that it reminded the visitors of the state of affairs in their own attics) to the Exploratorium, the science centre in San Francisco which is often taken as the beginning of the science centre movement.

To make my presentation accessible to a wider audience for whom the 2022 Michaelmas HAPP seminar is intended, I will not presuppose an intimate knowledge of the history of science museums; or the development of the various places where science has been presented to smaller and larger audiences and publics in the past.

I will therefore proceed in three parts. In the first part, a kind of prelude, I will present a brief sketch of the long history of scientific instruments, demonstrations and models that have been harnessed in various ways and places to demonstrate and explain science since the scientific revolution. Then I will look at the emergence of major national science and technology museums in the early 20th century. Finally, the post-war revolution in the objects of science communication will be presented in some detail.

## 2. Objects of science and science communication 17th to 19th century

Beginning in the seventeenth century and epitomised by the Royal Society in London and the Academie des Sciences in Paris, experimental natural philosophy took off and was communicated to an ever wider audience. Not only through the new journals and public lectures, but also through casual discussions in the then fashionable coffeehouses where scientists and laymen met. With the academies came cabinets of scientific instruments, and in this fine drawing of the cabinet of the Paris Academie des Sciences we see the wealth of material objects (Fig. 1).

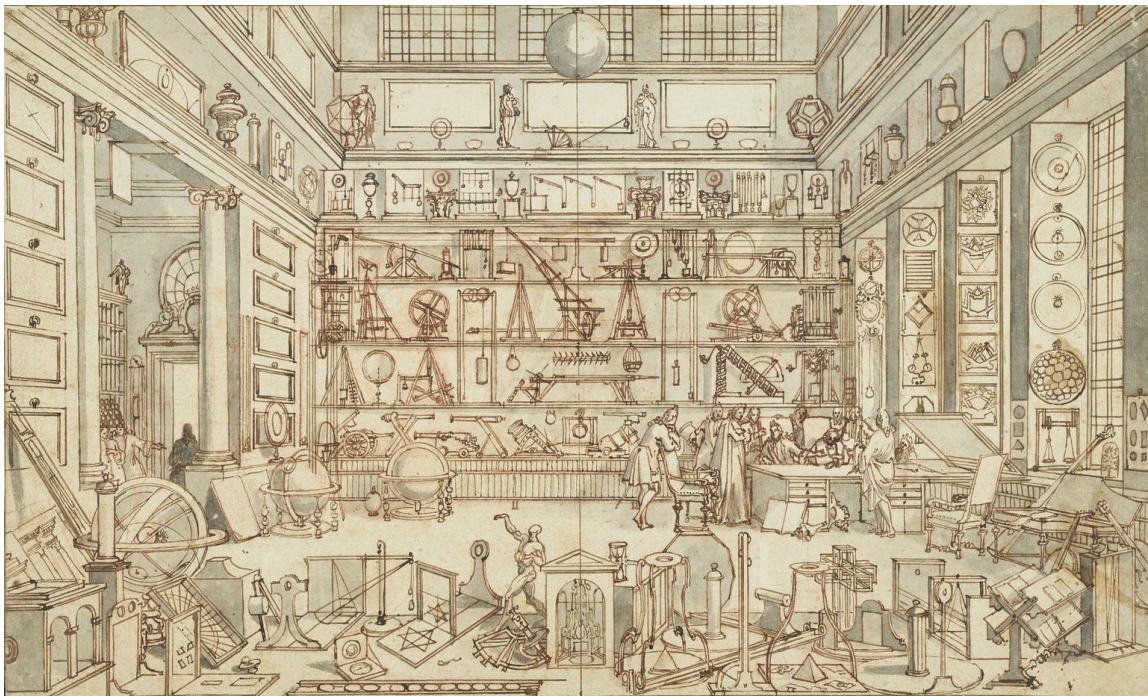


Fig. 1. Sébastien Le Clerc, The Physical Laboratory of the Académie des Sciences, c. 1711.  
Credit: Science Museum London (CC BY-NC-SA)

These collections were not open to the public – not yet – and in London, for example, people from the circles of the Royal Society, such as demonstrators, assistants or amanuensis, presented scientific phenomena to various audiences. Mostly for money and either in their own homes or as itinerant lecturers travelling from place to place.

An event that drastically opened up not only the aristocratic wealth with its art collections but also scientific objects to the eyes of the public was the French Revolution. Because the new Republic wanted to make use of the grand collection of the Académie des Science, housed in the Louvre. Artisans and technicians should be able to study the best examples of scientific instruments and technological solutions in order to contribute to the new times with their own inventions. However, as the academy was seen as an institution of the ancien regime, it was shut down, in this way allowing the collection to become part of – what I would call – the first science museum, the Conservatoire des Arts et Métiers, in 1794.

At this point one could also discuss the case of the 1683 Oxford Ashmolean, in particular whether it reached a threshold for being a public science museum or whether it served more as a university with a basement laboratory, a 'school of natural philosophy' and a library, which I will not go into here [1,2].

A very different way of bringing science to the public emerged as a fashionable, if not competitive, enterprise in London in the first half of the 19th century. The Colosseum in Regent's Park, the Adelaide Gallery near Piccadilly Circus, the Polytechnic Institution in Regent's St and the like were private enterprises that sought to make money by exhibiting scientific instruments and gadgets to a shilling crowd.



Fig. 2. Great Hall of the Royal Polytechnic Institution, London, c. 1840, printed by CJ Cox, n.d.  
Credit: Science Museum London (CC BY-NC-SA)

As the 'National Gallery of Practical Science, Blending Instruction and Amusement' (so the Adelaide Gallery characterised itself, seen here on the left) or as the 'Gallery of Sciences' for 'the education of the eye' (the Royal Polytechnic, here on the right), they served to present scientific and technological advances in the centre of London. Demonstrations, hands-on experiences and theatrical shows provided the basis for a public culture of science. And a certain Professor Pepper became the best-known science presenter with his spell-binding projection techniques that created ghost illusions, a speaking decapitated head or invisible rays causing combustion. One could argue that these institutions were the science centres of the Victorian age [3-5].

Then, however, their business model went into crisis. This was because the visitors would only return for new attractions, which were costly, and also, the splendour of science and technology display at the Great Exhibition may have outshone their offerings. Selling science to an urban public in such ways – especially at times when people experienced a significant change in their daily lives through steam, engineering and electricity – also worked in Germany. However, Berlin was a relatively late metropolis. The 1888 Urania was a place to experiment first-hand with electricity and optical and acoustic phenomena. However, it was a stock company, not a public or state-funded museum, and it had a similar fate as the shows of London earlier [6].

### 3. The Science Museum as a National Institution

It might have become already apparent that I reserve the term ‘science museum’ to institutions of particular importance, especially of national importance. Then, with their competitive nature, great international expositions and the World’s Fairs stand at the beginning of national science museums like the Deutsches Museum in Munich or the London Science Museum. In London, for example, there was a direct line of development from the remaining collections of scientific apparatus from the Great Exhibition to the opening of the Science Museum in 1909. Only, in the preceding fifty years, the British had been much more interested in arts and crafts or natural history than in science. Eventually, combining the collections left from South Kensington’s Crystal Palace with the holdings of a Patent Office Museum and additional objects and copies from other European collections, which came to London with a so-called Special Loan Exhibition in 1876, the Science Museum emerged. Clearly, a particular motivation, if not incitement, was the opening of the Deutsches Museum in Munich in 1906.

So now the big science and technology nations had prominent science museums. In France, the Conservatoire had become Conservatoire National des Arts et Métiers, and the Smithsonian Institution presented its collections on science and technology in the United States National Museum. One might add Vienna, Prague and Moscow.

This combination of science and technology display with the celebration of national might necessitated a recalibration of attitudes towards scientific material objects. Probably, most clearly visible at the Deutsches Museum, whose full name was Deutsches Museum von Meisterwerken von Naturwissenschaft und Technik – of masterpieces of science and technology. Like the arts, science and technology have also produced masterpieces. And these masterpieces required the same attention and appreciation; this was the credo of the museum founder Oskar von Miller. Through a reversal of logic, it was argued that natural scientists and technicians should finally be given the same prestige as artists, composers or literary figures. This new recognition of science and technology was reflected by the architecture and the presentation of the artefacts, as many iconic images from Munich and London show.

Now, the stage is prepared on which my main story can unfold: Obviously, most of the entertainment and playfulness of science display we have found in earlier times have given way to the new prevalent mode of science presentation: appreciation and awe. As a result, the room for excitement and first-hand experience was now rather limited. However, we should keep in mind two lessons from the earlier development.

First, it was probably part of the founding narrative of all museums and institutions that were meant to communicate science and technology to the public that they have invented a brand-new method to facilitate learning and understanding. However, most of the promises of new ways to see, handle, feel, interact with or participate in science turned out to be, in large part, a revival or remake of interactivity, hands-on and immersive experiences that were sometimes used centuries ago. So: Interactivity, hands-on and immersive experiences are *not* the invention of the latest science centre but have been around for long [7].

And secondly, there is not only black and white. One can celebrate masterworks while entertaining motion and interactivity at the same time. Actually, it was part of the method devised for artefact display at the Deutsches Museum to offer a combination of objects to the visitor. Exemplified for the water-column engine by Georg Friedrich von Reichenbach, an ideal exhibit would consist not only of the masterwork itself. If possible, the original historical engine, would be combined with a cut model (or at least a cut drawing) of the artefact, a plan of the entire installation for water lifting, and a glass model of the machine that could be operated by the visitor (Fig. 3). So already in the early planning phase of the museum of masterworks, interactive exhibits had been included [8]. However, they were secondary. They were meant to illuminate the artefact and to expound its importance. They were not meant to stand on their own.

One can already see the point I will try to make later: the revolution in science display will make the experience of the natural or technical phenomenon primary and will not care so much – or not at all – about the actual realisation in a machine or a historical artefact.

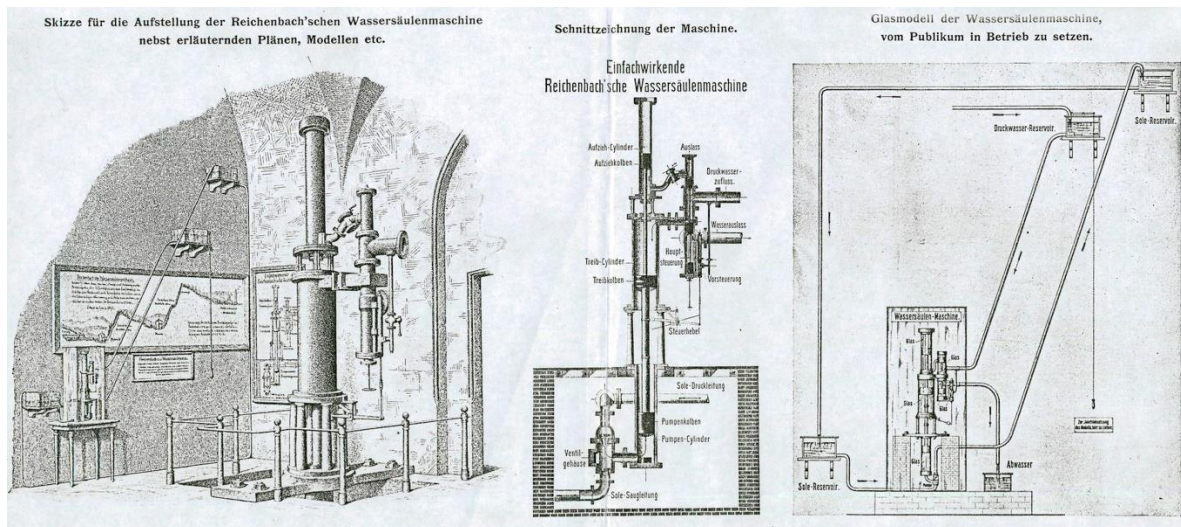


Fig. 3 Exhibit concept for a water column engine for the Deutsches Museum from 1903. General layout (left), a cut drawing (centre) and a visitor-operated model (right). From: Deutsches Museum, Verwaltungsbericht 1904. Credit: Deutsches Museum Archives.

A similar conclusion can be drawn for the London Science Museum, which opened a Children's Gallery in 1931, and which might at first sight appear to be a forerunner of the modern science centre experience. However, the concept was very different. The Children's Gallery, also understood as a general introductory gallery, was meant to 'be scaled down to the juvenile intelligence' – or to that of a member of the working-class – and 'would tell the same story as the main collection but in a very simple form' [9]. Having learned their lesson, these visitors would then be taken to the main galleries. Thus, interactivity did not enter the science museum per se, or in its own right. Instead, it was a means of preparing the young and uneducated for the historical artefacts in the main galleries. But again, the aim was to appreciate the inventions and discoveries of the great men of science.

#### 4. The Revolution in the objects of science communication

I have now reached the main theme of my talk. Although all the ingredients for something like an interactive science centre for kids and everyone can be found in Europe, it was in North America that the science museum was re-invented. In the following I focus on the US and leave out the equally important developments in Canada [10].

##### 4.1. From Europe to the United States

First of all, it won't come as a surprise that all the American science museums were built more or less along European models. The buildings alone – whether in Washington or Chicago – show that the idea of a great national museum for science and technology, or for science and industry as they were usually called in the US, was adopted. In fact, whole departments of the Chicago museum were close copies of the Deutsches Museum, notably, the coal mine in the basement. The reason Chicago's Museum of Science and Industry may have surpassed the Smithsonian as the national science museum for some time is the latter's lack of innovation, nicknamed the Attic of the Nation. The 1933 Century of Progress Exhibition in Chicago and the exhibits organised for it also helped to establish a permanent museum (so one can see some similarities with London).

When the Smithsonian finally opened a huge new museum of history and technology in 1964, it not only reclaimed the leadership role from Chicago, it also linked technology and the nation in a particularly powerful way, symbolised in the entrance hall where a Foucault pendulum swung in front of the Star-Spangled Banner, the early flag that became a prominent symbol of the nation (Fig. 4). As

modern as the building might appear from the outside, visitors to the museum could hardly tell whether they were in a museum of technology from the beginning of the century or in postwar America. Were it not for a few contemporary objects, such as a satellite or a fusion reactor, they would probably not have noticed much difference.



Fig. 4 Foucault pendulum in front of the Star-Spangled Banner in the Smithsonian's Museum of History and Technology. Credit: Smithsonian Institution Archives (CC0)

#### 4.2. *Californian Innovations in Science Display*

The main point I would like to make in this paper is that we have to look west, to California, in order to find the beginning of the revolution in the objects of science display, and we have to include politics, particularly the Cold War.

The Museum of Science and Industry of California in Exposition Park, Los Angeles, is obviously a lesser-known institution. But it was the first postwar project for a new science museum in the US. And it emerged in the specific postwar context, which for Southern California meant a military and industrial boom as the political focus had shifted to the Pacific. Military spending and the technology industry in particular created an interest in, and wealth from, science and technology. In this context, an outdated agricultural exhibit was transformed into a Museum of Science and Industry.

Its rationale was well expressed in a brochure: The exhibits of the Museum of Science and Industry of California 'combine entertainment and sugar-coated education. The purpose ... it to send every visitor away knowing more about the State's economy and industry, and thus better able to contribute personally to its future development. To do this, every modern technique of drama, color and lighting is employed.' [11]

In the beginning, the museum took over industrial and fair design, mostly sponsored by big corporations, as this had been the case already in many Museums of Science in Industry since the 1940s like in New York, Boston and Chicago. Here in Los Angeles, new approaches to science communication

in museums were developed. In 1960, the LA Times reported, the latest one was storytelling. The museum would tell a story through its exhibits. In doing so, it would avoid becoming the typical clutter-case museum that just collects and displays about everything, of which the Smithsonian was the daunting example [12]. Probably this approach was also motivated by Walt Disney's storytelling about 'Our friend the atom', dinosaurs, future worlds etc., that was used at World's Fairs and Disney Theme Parks. Storytelling would stimulate young people towards careers in both science and industry, so it was seen.

However, a seminal exhibit on mathematics called MATHEMATICA introduced a completely different approach just one year later in 1961, which one could summarise as 'Don't tell stories, exhibit ideas!' And this is also a very Californian development, as MATHEMATICA was built by Charles and Ray Eames – an American couple of designers, architects and filmmakers. They are best-known for their chairs; here, however, their impact as exhibit designers and filmmakers will be decisive. Simply put, their achievement in the history of science display is the change from exhibiting objects of (past) science to exhibiting ideas and concepts of science. And the 1961 MATHEMATICA exhibit can be seen as the game changer. Crucially, this approach generated new objects of science to be displayed – the ones I call edufacts [10, 13].

#### 4.3. Information Overload and Interactivity

Before I discuss to the new objects of science communication in more detail, I should introduce some key concepts of the Eameses for idea communication. On the basis of vast research into a topic, e.g. mathematics, the Eameses created history walls and image walls. Like a hypertext structure, many information items are multidimensionally arranged and linked. There is no one linear reading of the information anymore, and every visitor has to decide how to navigate the information, or rather, how to select some bits and pieces because it was simply too much to digest. The visitor is made to select from the plenty and is shown the whole lot at the same time; in this way a sense of the richness and the whole of the subject is conveyed.



Fig. 5 MATHEMATICA exhibit with image wall, history wall and objects.  
Photo of the Boston exhibit in 2021. Credit: A. Schirmacher

By talking to experts, in this case, Los Angeles mathematicians, the Eameses and their office staff tried to understand the main ideas themselves, at least to some extent, before attempting to translate this idea or insight into an exhibit that embodied it. This process also led to a number of interactive exhibits that

were not based on historical objects or instruments from demonstrations but were designed to allow visitors to experience key mathematical and scientific concepts in a playful way [14].

For example, celestial mechanics and thus Kepler's laws, were demonstrated using a kind of pin-ball machine. While watching the ball's orbit, an explanatory text comes into view on the edge of the device. The positioning of the exhibit in the middle of the floor creates a communicative situation in which visitors can observe the phenomenon from all sides of the machine and, at the same time, view the reactions of fellow museum-goers. Similarly, the 'Probability Machine' can be observed from two sides. This is a push-button exhibit that allows visitors to follow how the Gaussian distribution emerges from a process of averaging. Other interactives include the Moebius strip, the one-sidedness of which is demonstrated by an arrow that, when activated, travels along the surface of the strip. And yet another push-button exhibit makes minimal surfaces visible by dipping a wire body in soapy water.



Fig. 6 MATHEMATICA Pin-ball machine to demonstrate celestial mechanics.  
Photo of the Boston exhibit in 2021. Credit: A. Schirmacher

Yet, it is important to emphasise that the Eameses were not scientists and, strictly speaking, and also not science communicators in the narrow sense. They were interested in many things, obviously, but first and foremost they were communicators of ideas with their exhibits and films. And there was a demand for idea communication from politics, from industry, and from people who wanted to implement a new image of US science.



#### 4.4. Promoting a New Concept of Science

The Eameses were incredibly successful at international and World's Fairs. For example, the 1962 World's Fair in Seattle featured a huge U.S. Science Exhibit – almost the size of a major science museum. A multiscreen projection *The House of Science* stood at the beginning of a visit which employed no less than six huge screens that were used to show not one object, building or person but six versions thereof at the same time. The method had been used at an American exhibition in Moscow three years before, presenting the American life to an audience beyond the iron curtain. A gist, the idea, or a generalisation of the American life was communicated by showing not one but, at this instance, seven freeway junctions or seven suburban houses with swimming pools. Similarly, in Seattle, the simultaneous projection of six observatories, six scientists in the lab (Fig. 7), or six atomic models conveyed the general idea of an observatory, the scientific persona, or the atomic structure in general. Later at the 1964 World's fair in New York the Eameses created an even more elaborate three-dimensional projection environment to communicate the essence of the computer as a universal machine, an exhibit commissioned by IBM. How this all worked has been documented on film [14].



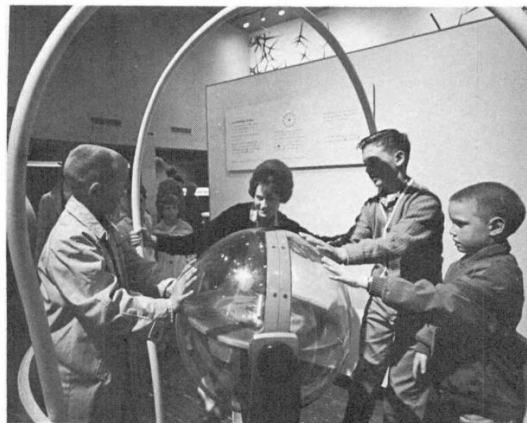
**"These are the men that inhabit the House."**

Fig. 7 The film *The House of Science* presented at the 1962 Seattle World's Fair employs multiscreen projection to create the idea of a (male) scientist. Credit: U.S. Department of Commerce [15]

In 1962, the U.S. Science Exhibit promoted a new idea or a new concept of science that the US wanted to communicate. Why this was done exactly to a World's Fair crowd at that time can be learned from the final report of the Science Exhibit: it was meant to be an answer to the crisis Sputnik and the successes of the Russian space program had created. It had become clear that '... something such as an International Science Fair was badly needed to demonstrate the many areas in which US science was preeminent, and to awaken the US public to the significance of the general scientific effort...' [15] This was the context in which the Eameses promoted an image of science, one that was characterised by a speaker from the off as follows: 'Science is essentially an artistic or philosophical enterprise carried on for its own sake. In this it is more akin to Play than to work. But it is quite a sophisticated Play in which the scientist views nature as a system of interlocking puzzles....' Science had therefore nothing to do with industry and the military, where, however, at that time most physicist worked; science was fun and satisfaction for lucky researchers (Fig. 7). But is science really a play like jigsaw puzzle solving? [16]

Clearly, Thomas Kuhn's book *The Structure of Scientific Revolutions*, which just had been published before the Fair, gives these lines a familiar ring, as he claimed that puzzle-solving was the typical pursuit of most scientists. That is, a somewhat rewarding 'normal science', in which playfulness and artful procedures solve the problems, or puzzles, that are somehow manageable for bright scientists such as those produced in the USA [17]. And no other than Kuhn had been the primary consultant to Eames Office for this project.

One of the six areas of the science exhibition, the Junior Laboratory of Science, features interactive exhibits that look very similar to those in *MATHEMATICA* (Fig. 8). Pinball machines as atomic colliders, a moonshot reminiscent of the celestial mechanics exhibit, and the like. It turns out that the Junior Lab was not designed by the Eames Office, but by two other Californian designers, who, however, came from the Eameses and were part of a designer network of (so-called) sunbaked modernists: Frederick Usher and John Follis, the latter having already worked on the *MATHEMATICA* exhibit. But this line of new edufacts by Californian designers is only part of the story of the revolution in the objects of science communication. Sure, the old stuff of original artefacts has given way to new objects.



**The Gyroscope Exhibit (No. 12)—One of the most popular exhibits.**

Fig. 8 Hands-on exhibit in the Junior Laboratory of the 1962 U.S. Science Exhibit.  
Credit: U.S. Department of Commerce [15]

#### *4.5. Curriculum Reform, MATHEMATICA and the Science Centre*

The second line, which produced new edufacts, was part of the curriculum reform projects that started after the war and were accelerated through Sputnik. The Physical Science Study Committee (PSSC) worked to improve high school education and the Elementary Science Study (ESS) that of elementary schools with programs to improve science teaching. Frank Oppenheimer, J. Robert's brother, was involved in implementing the PSSC physics course and devised the idea creating a library of experiments – of the important ones one should have performed to understand physics – 'in which the apparatus for an experiment is nearly as accessible as the books in the stacks of a university library.' Moreover, these experiments could be checked out like books in a library [18]. While the experiments were carefully prepared to make it easy to produce the physical phenomenon, there was still a degree of flexibility built in, making them much more puzzle-like than the push-button exhibits at *MATHEMATICA* or in Seattle.

A few years later Oppenheimer started to create a new kind of science museum in San Francisco that, among others, included some of the items from the library of experiments. More importantly, it translated the concept from teaching devices to museum exhibits. The idea was to provide the visitor an experience with rough and ready-made objects that were built in the museum's own workshop. There was no discernible design concept, and the place was more of an open space with seemingly randomly

distributed exhibits. Some of the exhibits, many of which have become iconic in the world of science centres, have their roots in the curriculum projects. The Light Island exhibit, for example, allows visitors to freely move various optical elements to figure out and experience optical phenomena. It has evolved from the Optics Table, a unit in the ESS school kits. [19] Science Centres such as the Exploratorium would constantly try to improve their exhibits. And since they are mostly made from inexpensive material and in their own workshop, this can easily be accomplished.

A further ingredient of the science centre concept and a stark deviation from that of a typical museum is that the Exploratorium championed sharing its edufacts. In fact, they published so-called Cookbooks with dozens of recipes so that, in principle, everybody could reproduce them and open his own science centre. From this approach quickly, a science centre movement emerged, and people from the Exploratorium helped to create similar places all over the US. As a collaborator of Oppenheimer put it, they were fanning the flames [20].

## 5. Outlook

Let me conclude with a brief sketch of how the new kind of science museum, the science centre, found its way to Europe, and to Britain in particular. Here it was Richard Gregory, the Bristol neuropsychologist and educator, who probably became a household name in 1967 when his Royal Institution Christmas Lectures, 'The Intelligent Eye', were broadcast on the BBC and later published as a bestselling book under the same title [21].

Gregory's relationship with the Exploratorium was close, he visited the place, and his book was an inspiration for exhibits in San Francisco. However, it was not until 1983 that he opened his own version of a science centre, the Exploratory in Bristol. Their website provides a brief history of the new approach to science display, presenting Francis Bacon as the inventor of the science centre concept, Oppenheimer as the first creator of one, and Gregory as the one who brought it to the UK. The Exploratory is now gone; in 2000 @Bristol ousted Gregory and his museum, and in 2017 it was rebranded as 'We the Curious' (and at the time of writing this science centre it is closed).

In 1986, the science centre movement also conquered London when the Science Museum opened its Launch Pad, a 900 square metre gallery that quickly drew 800.000 visitors a year, or over 2000 a day. In London, visitors thus had the possibility to compare both the museum experience with its precious artefacts in glass cases and the science centre experience with its interactivity and hands-on approach in one institution. Ironically, as some people had discovered, the same phenomena were sometimes treated both in the Launch Pad and, for example, the King George III Collection of 18th century scientific instruments and demonstration apparatus. Only this was done with an edufact in the Launch Pad and with a historical artefact in the Collection. Typically, however, visitors voted with their feet and went to the Launch Pad in much greater numbers if they could get a timed ticket.

For the Science Museum in London, and similarly for some other great national museums of science and technology such as the Deutsches Museum or the Smithsonian Institution, the science centre movement did not threaten the existence of these institutions, but science centre display was sometimes combined or incorporated. This was the privilege of the powerful few.

From a more global perspective, and looking at what new institutions are being opened regionally to communicate science and technology, it is mainly the science centre that has replaced the artefact-based museum of science and technology. I can only hint at the problems that this development poses [22]. We have seen how edufacts have been used to promote a new image of science as an artistic and philosophical enterprise, while at the same time the main employment of scientists during the Cold War space race was in industry and the military. Shielded from these realities, a mere display of colourful phenomena, playful experiences and incredible perceptions leaves out much of what science actually means to modern societies. In this respect, the artefact is more stubborn, as its context, its uses, its creator and its historical pathway cannot be stripped off but remain in the object to be discovered and discussed.

## References

- [1] Abt J 2006 'The Origin of the Public Museum' *A Companion to Museum Studies*, ed S Macdonald (Oxford: Blackwell) pp 115–134
- [2] Füssel M 2015 'Lehre ohne Forschung? Die Praxis des Wissens an der vormodernen Universität' *Akademische Wissenskulturen. Praktiken des Lehrens und Forschens vom Mittelalter bis zur Moderne*, ed Kintzinger M, Steckel S (Basel: Schwalbe) pp 59–87
- [3] Altick R 1978 *The Shows of London* (Cambridge: Belknap)
- [4] Society for the Illustration and Encouragement of Practical Science 1836 *Gallery for the Exhibition of Objects Blending Instruction with Amusement: Adelaide Street, and Lowther Arcade, West Strand. Catalogue for May, 1836* (London: William Clowes)
- [5] Weeden B 2008 *The Education of the Eye: History of the Royal Polytechnic Institution 1838–1881* (Cambridge: Granta)
- [6] Bleyer U, Herrmann D 2013 *125 Jahre Urania Berlin* (Berlin: Westkreuz)
- [7] Griffiths A 2008 *Shivers down your spine. Cinema, museums, and the immersive view* (New York: Columbia UP)
- [8] Deutsches Museum 1907 *Führer durch die Sammlungen* (Leipzig: Teubner)
- [9] Nielsen K 2014 "'What things mean in our daily lives": a history of museum curating and visiting in the Science Museum's Children's Gallery from c.1929 to 1969' *Brit J Hist Sci* 47 505–538, quote on p 512.
- [10] Schirmacher A 2019 'North-American World's Fairs and the Reinvention of the Science Museum in the 1960s', *Behind the Exhibit. Displaying Science and Technology at World's Fairs and Museums in the Twentieth Century* ed Canadelli E, Beretta M, Ronzon L (Washington: Smithsonian) pp 158–181.
- [11] Museum of Science and Industry of California 1951 *Museum of Science and Industry of California* (Los Angeles: Museum of Science and Industry of California) p. 3
- [12] Seidenbaum A 1960 'Once Stuffy Museum, Now Magic Teacher' *Los Angeles Times* 16 May 1960 p L2
- [13] IBM 1964 *Mathematica: A World of Numbers . . . and Beyond* (Los Angeles: IBM)
- [14] Neuhart J, Neuhart M, Eames R 1989 *Eames Design: The Work of the Office of Charles and Ray Eames* (New York: Abrams) pp 254–259
- [15] Department of Commerce 1962 *United States Science Exhibit. Seattle World's Fair. Final Report* (Washington: Dept. of Commerce) p. 3, 8 and 40.
- [16] *The House of Science* 1962 film of Seattle U.S. Science Exhibit, <https://youtu.be/ivuOyD1BIH0> (27.09.2023)
- [17] Kuhn T 1962 *The Structure of Scientific Revolutions* (Chicago: Chicago UP)
- [18] Oppenheimer F, Correll M 1964 'A library of experiments' *Am J Phys* 32 220–225
- [19] Oppenheimer F et al 1986 *Working prototypes. Exhibit design at the Exploratorium* (San Francisco: Exploratorium) pp 20–23
- [20] Semper R 2006 'Fanning the Flames: The Exploratorium at the Birth of the Science Center Movement' *Handbook for Small Science Center* ed Yao, C (Lanham: AltaMira) pp 252–255
- [21] Gregory R 1970 *The Intelligent Eye* (New York: McGraw-Hill)
- [22] Schirmacher S 2019 'Das Wissenschaftsmuseum als „politische Maschine“ und seine Transformation im 20. Jahrhundert' *Acta historica Leopoldina* 74 107–132