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## Editorial

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### **Public perception of science. Part 1**

Can science be made attractive and understandable to a largely unscientific public? As accounts of science depart ever more dramatically from common-sense appearances, perception of science becomes increasingly important for science-based societies and for individuals aimed at the future. One approach is hands-on Science Centres.

Presenting science through hands-on exploration has concerned me for many years—from helping Frank Oppenheimer shortly after the start of his celebrated *Exploratorium*, in San Francisco in 1969, to the founding of the first hands-on Science Centre in Britain, the *Exploratory* in Bristol, ten years later. Many Centres of various kinds have now appeared around the world, including almost all European countries and fine examples in Australia, Canada, India, and Singapore. The many American Centres are a billion dollar industry and receive generous public support. In Britain, hundreds of millions of pounds are being spent on grand new Centres initiated with Lottery and Government funding, though continuing support is not promised.

Advancing understanding of science must be good for societies and individuals; but there are questions: What can Science Centres add to schools and universities? How should they relate to traditional (hands-off) museums? We may ask more parochially: Can understanding of perceptual processes help to guide their designs?

To my mind, the Exploratorium in San Francisco remains the most successful no-frills Centre. Its history and philosophy are described by Hilda Hein (1990). From the Introduction (page xv) is its founder Frank Oppenheimer's credo:

"Museums usually house static displays to be admired from a distance. Even natural history collections, the primary contents of science museums, tend to require only a passive and reverential appreciation of the odd and various specimens someone has painstakingly assembled. Such exhibits can strike wonder at the right diversity of the universe, but they tend also to encourage awe for the brilliance of the few adults who have been able to unravel its complexity. Science museums often glorify scientists more than they teach museum goers the practice of science. Visitors are invited to admire the accomplishments of others, but not always to think that they might go and do likewise.

The proposal that Oppenheimer brought [to San Francisco] was for a museum in which people would directly experience and manipulate things, instead of being told about them. The public was to interact with objects as an experimental scientist does in the natural world or in the laboratory. The museum was to teach that the subject matter of science is all around us and that its comprehension is available to all. It was to remove science from the exclusive domain of experts, to demystify it, and to restore it to the common sphere. It was to convince people that doing science can be interesting and fun for everyone."

Shortly after its opening in 1969, I happened to give a lecture in San Francisco (the first Smith-Kettlewell Lecture, on illusions) and so met Frank Oppenheimer. He was attracted to perception and illusions as a theme for the Exploratorium (and very likely had already thought of it), so he asked me to design perceptual experiments, and to discuss in depth the philosophy of the whole enterprise. Hein (1990) describes what happened (pages 7–8):

"Visual exhibits were among the first to be constructed in the museum, and they formed the first coherent exhibit section ... . On the one hand, it expounds a perceptual theory, essentially that explained by Richard Gregory in his book *The Intelligent Eye* (1970). On the other, it reveals an emerging exhibit strategy whose principles became more clearly defined in the process of constructing the exhibits.

Interaction is an important ingredient of both the visual theory and the exhibit strategy. Gregory's theory holds that visual perception is a complex integration of the observer's internal structures and interactive dispositions with the stimuli that originate externally. The Exploratorium's strategy is to let visitors be the subjects of their own perceptual experiments. By interacting with the museum exhibits, which provide the stimuli and the tools for observation, the subjects are able to analyse the visual process as it takes place within themselves."

This remains central in the Exploratorium in San Francisco, and was the basis of our Exploratory in Bristol, ten years later.

### **The Exploratory in Bristol, UK**

The Exploratory was conceived and planned in the late 1970s, made possible with initial funding from the Nuffield Foundation and from David (now Lord) Sainsbury and the Gatsbury Trust. We received no local or government funding. The annual turnover rose to about £1 000 000. Situated in the world's first major railway building—Temple Meads, designed by the great Victorian engineer Isambard Kingdom Brunel—it attracted over 2 000 000 visitors in its last ten years, 60% of whom were children. The Exploratory aimed to present significant phenomena simply and clearly with hands-on exploration. It was run on a shoestring, but was very popular, with children returning again and again.

No doubt each country and area has different problems, possibilities, and needs. Together with the successful *Techniquest* in neighbouring Cardiff, we showed that a no-frills science-based Centre could be financially viable (with a bit of help from time to time) in South West England and Wales. What will happen financially with the new generation of far larger and more lavish Centres, with their huge overheads? Is it right for large founding grants to be awarded without promise of continuing support? The more ambitious and expensive the building, the harder it must be to run it while maintaining academic standards. Will the new Centres have to become commercial enterprises to survive? There are strong forces dumbing them down, making them cosy and bland without the excitement and challenge of science—when surely it is dumbing *up* that is needed. They must, however, be understandable and not intimidating: the ideal is a healthy balance.

The Exploratory closed in 1999. Why? Bristol had received a Millennium grant of about £100 million, for *Wild Screen*, a Natural History Centre with an Imax cinema, and a grand Science Centre, *Explore*. Sadly, this magnificent development, which enhances the City, swamped our Exploratory, rather than developing it. As Bristol is too small for two Science Centres, we had to close. One hopes the increased scale will not inhibit hands-on science in *Explore*.

### **The eyes have it—for museums—or do they?**

Science Centres are not museums, as they do not protect and display precious objects; instead they offer active experiments and demonstrations of phenomena of nature, and discoveries and inventions, together with something of how science works. Museums offer primarily *visual* experience, which is essentially passive—as reflected, indeed, in the museum word 'exhibit'.<sup>(1)</sup> The Exploratory abandoned 'exhibit' in favour of its own made-up word *Plore*—something to be explored.

As museums provide almost entirely visual experiences, their designers should ask: what can visitors see in glass cases? Will they be effectively blind to unfamiliar objects? For example, how much do most of us see in fossils? Experiments are needed here. In their absence, I shall guess the results from my philosophy of perception, which might suggest some useful experiments. In short:

<sup>(1)</sup> Although in the 14th century 'exhibit' meant to *hold*, from the Latin *exhibere*, and the French *ex* – *our* + *habere* = to hold, it came to mean to *display* on view.

- (1) Perception of objects depends on knowledge. This extends back to early evolution, when vision depended on inherited knowledge, for instinctive behaviour with reflexes and tropisms. Inherited knowledge is gained by the life–death lessons of natural selection, and stored in the genetic code. It is the genetic code that learns.
- (2) Individual learning from experience is stored neurally, and is not—as Lamarck was wrong—transferred to the genetic code.<sup>(2)</sup>
- (3) Eyes are useful, when their brains can read *non*-optical properties from the optical images. (One cannot eat, or be eaten by, a retinal image—it is objects that matter.)
- (4) Meaning is projected into the world of objects, from knowledge or assumptions. Without inherited or individually learned knowledge, organisms are effectively blind.
- (5) The hands-on thesis is that non-optical knowledge for seeing comes from the proximal senses and especially from interactive touch.
- (6) This leads to the idea that hands-on Science Centres should help children to see and understand more richly, perhaps to continue learning to see and understand throughout adult life.

#### **Why do we need hands-on Science Centres?**

If children learn to see from hands-on experience of objects around them, why do they need the special objects (Plores) of Science Centres? The point is that the normal world is not a good Science Centre, for revealing underlying principles. This is why, indeed, they are ‘underlying’. A classical example is friction, which makes it hard to realise that objects should continue to move forever without an applied force. It took the genius of Galileo and Newton to realise that Aristotle, and all his millions of followers over the next two millennia, were fundamentally wrong. Newton’s First Law (that objects keep moving at constant velocity in a straight line, unless affected by an external force) is deeply counterintuitive, for it is not what we normally experience. Another famous example is heavy objects falling faster than lighter objects. This still seems obviously true, though, as we all know, Galileo showed it to be false in the absence of effective friction. Perhaps we still think of biased coins in terms of Aristotle’s intuitive but false physics! It is amazingly easy to slide back into intuitive Aristotelian physics (Wolpert 1992).

Phenomena of perception and illusion are especially popular in Science Centres. The history of science is a useful guide for choosing many basic experiments: Galileo’s tracks with rolling balls for investigating gravity; Newton’s experiments on light and colour; Faraday’s 1831 experiment on generating electricity with a magnet and coil of wire, and his beautifully simple motor, are examples that immediately come to mind. They are effective for the public, as they originally captured the imagination of scientists, to change the course of science itself. The challenge now is to discover how new ideas such as counterintuitive quantum theory can be presented effectively—perhaps to be understood better by children than by adults.

#### **What do visitors learn?**

It turns out that experiments and demonstrations presented simply and clearly compel attention, and indeed evoke excitement in almost all children and many adults. The Centre should not be ‘overdesigned’. The phenomena should speak for themselves.

Doubt is sometimes expressed in the frequent question: How much do visitors actually learn? As queried by Michael Shortland (1987), are hands-on Science Centres more than fun-fairs? My immediate answer would be there is interesting science in fun-fairs. There are interactions with gadgets and phenomena, subtle probabilities to judge, as well as human behaviour to observe, and much more to challenge the curious. The ‘Magic swing’

<sup>(2)</sup> The most dramatic demonstrations of the power of knowledge for vision is the ‘hollow face’ illusion: a hollow mask appearing as a normal convex face (Gregory 1970). A hollow face is so improbable that this unlikely ‘perceptual hypothesis’ is rejected, though true.

is a powerful, interesting illusion. The physical forces experienced on roller-coaster rides and even free-fall from a tall tower, are ambitious experiments that challenge physicists and engineers. They are frightening and yet popular, which is interesting psychologically. Does this reflect pre-human experience, stored in the genetic code?

How do we know whether Science Centres are effective? Clearly they can be attractive and motivating—this is obvious from the visitors' behaviour—but how much do visitors actually learn? Formal tests, with control groups and all the rest, are not easy as we should look for more than answers to quiz questions. After trying it with local schools (looking for improvement in pupil's essays, following a visit to the Exploratory), we gave it up as we lacked the necessary resources, skills, and time. It may be useful to suggest signs of understanding, to be observed in the behaviour of visitors:

### Signs of understanding

*Prediction*—indicates at least a partly valid hypothesis, or understanding.

*Surprise*—shows there is a predictive hypothesis—though not entirely appropriate.

*Analogies*—may be from surface appearance or may show conceptual understanding.

*Inventing*—shows creative gap-filling from surface or deep analogies.

*Seeing jokes*—shows social understanding, for jokes always have human connotations.

*Small effects*—when appreciated, the visitors show interest, and probably understanding.

*Nothing*—appreciating nothing happening is the clearest sign of a deep understanding.

We observed all these signs of understanding, on a good day. Introducing surprising phenomena is very important. Favourites are the counterintuitive Bernoulli phenomena, leading to flight. Surprise is a self-signal for lack of understanding, and evokes curiosity. It is especially rewarding to see children captured by surprise at *nothing* happening. The classical example in adult science is the Michelson—Morley experiment, in which nothing happening shows that the 19th century ether was a false fiction. Quite young children are surprised that a loaded barge does *not* increase the weight on an aqueduct, though a train increases the loading on a bridge. Once they think about the no-change of the aqueduct, they understand the nature of floating more fully. However, most kids do prefer loud bangs to nothing happening!

### Explanations

Science Centres can extend science-play, in depth and through life, with more sophisticated 'toys' and fuller explanations. In our terminology: 'Hands-on' experience leads to 'Hand-waving' explanations. Though informal, they are often useful and may be all that is needed. They can lead to formal structured explanations. When these include mathematics we might call them 'Handle-turning' explanations.<sup>(3)</sup> But, of course, mathematics is more than handle-turning. As an aide-memoire, we have:

#### *Handles: Three kinds of experience and explanation*

*Hands-on*            Explorations            Empirical basis of perception and knowledge

*Hand-waving*       Explanations            Often adequate though informal

*Handle-turning*    Computations            Mathematics for quantifying

The first is the core of a hands-on Centre. Most explanations will be hand-waving; but these are useful, and can lead to formal science, including handle-turning mathematics. Developing skills of mathematics is more in the province of schools and universities, but the concepts are appropriate for Science Centres and can be explored in interesting ways. In the dynamics of science itself, there is interchange between all these 'Handles'.

<sup>(3)</sup> This is from the 17th century invention of wheeled calculators. A gear-wheel computer was built by Pascal in 1642, the year of Newton's birth; programming being introduced two hundred years later by Charles Babbage.

### The role of computers

Computers were almost absent in the Exploratory as we preferred *real* demonstrations and experiments. But as technology advances, this must be kept in continuous review. Computer-graphics are now powerful and attractive; but one might, rather rudely, call pictures *eye-cons*. This, because they draw on past knowledge from past experience for brains to see them. They are not good at conveying *new* knowledge. Conversely, a simple cartoon can elicit a wealth of meaning, provided we already know what it is about. Cartoons show the importance of knowledge for perception, and the value and limitations of pictures.

Pictures are essentially limited, so what of computer-graphics for Science Centres? Dynamic processes help, and they may indeed show things impossible to produce with real objects. This is so for biology, physics, chemistry, and far more. Undoubtedly screens have an important place; but video and computer programs are subject to misleading editing and selection by their designers. There is nothing like the real world as a reliable source of information! But the real world is not always available. Television and computer-graphics can sweep through space and time, to bring unavailable realities and worlds of imagination. Wonderfully, the web gives instant communication to millions of people around the world.

A Science Centre should be based where possible on *real* demonstrations and experiments; but computer-graphics can sometimes be linked to touchable objects. Very simply in the Exploratory, we had coloured wooden balls for atoms to 'make' molecules, with a related computer display and knowledge base. This combined hands-on objects with a computer; its knowledge base giving the properties, discovery, and so on of the various molecules that could be 'made'. This worked well and could be developed.

At present 'goggles' virtual reality is disappointing, but it should have a significant future. It may allow us to try out future technologies and shake hands with alternative universes. Again, the key seems to be *interaction*. This can take us to experiencing abstract concepts. Philip Davis and Reuben Hersh (1971) give an early example in *The Mathematical Experience*. While trying to understand a four-dimensional cube, one of the authors experienced a dynamic computer display:

"I tried turning the hypercube around, moving it away, bringing it up close, turning it around another way. Suddenly I could feel it! The hypercube had leapt into palpable reality, as I learned how to manipulate it, feeling in my fingertips the power to change what I saw and change it back again. The active control at the computer console created a union of kinaesthetic and visual thinking which brought the hypercube up to the level of intuitive understanding."

As technology evolves further, it should be possible to interact in ever more interesting ways with computer-generated worlds. But let's start with objects and phenomena. We should not abandon reality for even the most amazing illusions.

### Conclusion

So-called 'Science Centres' which do not provide science may do serious disservice by suggesting that science is easy, even trivial, and does not need careful thinking and observation motivated by curiosity. It is a travesty to sail under such a false flag. Science Centres can be many things, and variety is good, but they must have *some* real science to justify their name and existence.

Hands-on Science Centres and more traditional museums, are both concerned with ideas. Museums have the benefit of fascinating objects from the past. Science Centres are more concerned with present activity. As there are overlaps, and neither is complete, surely each should help the other, to share ideas of science with the public.

Seeing objects depends on knowledge. When needed knowledge is not available, we are effectively blind. Thus a picture of neural structures is meaningless without some knowledge of what these are, and might do. With this knowledge the picture is illuminating, and may tell us more. This does not only apply to pictures: the lines of a spectrum are but meaningless patterns until one knows how a spectroscope works, to tell us what stars are made of.

Perhaps museums shy away from science as being too difficult. But visitors do not expect to understand everything at first sight (or touch). It is a sad waste of time and money to run a 'Science' Centre without science thinking. It should be presenting phenomena and experiments, and introducing explanations as hypotheses open to challenge by evidence and arguments. Indeed, there is little point developing education if there is not a corresponding increase in questioning and discovering, and planning futures. The media's assumption that attention span is limited to ten minutes is surely wrong; but may become true if sustained presentations and discussions are banned. Of course, attention span for boring programmes is limited; but when captured, interest can last a lifetime.

It should be confessed that, although science museums have wonderful things to see, they seldom present ideas or principles of science—so the visitor may be blind to its riches. This is the point (as I believe) of Science Centres, which lack the beautiful and historically interesting objects of museums, but, through first-hand experience, reveal the nature of Nature.

Is it possible that more academic values of curiosity and questioning are growing to reach the point where science for the public will be commercially viable? As the movement grows, so the public should support with increasing generosity centres presenting genuine science. Long-term, we might hope that the commercial world itself will come to take on more academic standards. Then, at least in our terms, money will have more value. For there will be more interesting things to buy and do. The same money will be worth more, so we will all be wealthier! Wealth is, of course, very different from money.

Science Centres, with museums, may become secular cathedrals of the future. Benefits and dangers of science and technology will be debated with the public to share considerations of where we aim to go, and how to get there. But they must be planned with a significant philosophy, and should be allowed to evolve by experience. They should do research: especially on public perception of science, and science perception of the public.

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