Beyond Hands-On:
Truth-telling and the Doing of Science

"The real truths are those that can be invented"
Karl Kraus

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Introduction

In the early years of the Royal Society, shortly after the Restoration of the monarchy in the mid-1600s, science was largely the domain of a small group of gifted amateurs, of gentlemen with an abiding passion for enquiry. In these early days of rationalist science, as now, proof was often a matter of witnessing, of actually seing a result predicted by theory. Fundamental to the act of witnessing, however, was good faith, and a shared ability and competence to witness. This meant that in the houses of experiment of the late seventeenth century, although the public could be invited to watch experiments being tried, only gentlemen could corroborate the scientific work of other gentlemen, despite the fact that often the experimental apparatus was prepared by technicians other than the gentleman scientist himself. Witnessing was a measure of shared intent, of participation, and of exclusion. [1]

Since the high water mark of Renaissance Neo-Platonism, the tenor of scientific discourse in the West has been increasingly coloured by Aristotelian rationalism. One of the effects of this rationalism has been to constrain the role of the observer, and has often made the process of scientific education one of compelling consensus about the nature of observed phenomena.

Equally, as science museums are often built as expressions of contemporary views about science education and the corresponding role of science in society, they can provide us with insights into changes taking place in the formulation of the proper role of both the observer and the observed in scientific discourse.

Roughly speaking, we can speak of of the development of the science museum in the past two centuries as comprising three "generations", or approaches. These approaches are linked to more far-reaching social and political changes affecting the ways in which we view institutions in general, however, most of these changes fall unfortunately beyond the scope of this paper.

These changes occurring within the science museum often reflect similar changes that have taken place, often decades, and sometimes centuries earlier, within debates about the role of science and science education in the society at large.

I argue that, since the late Renaissance, the ascendance of a rational, mechanistic and largely secular science has shaped the way in which science has been defined and pursued. This approach to science found its built expression in the science museums of the late nineteenth century, which can be seen as a "fossil record" of institutional agreements about the nature of science and the world that it describes.

I propose that throughout the history of science, museums and their precursors, which is also to say the institutional stance, have lagged behind the contemporary scientific debate by up to one hundred years. For example, neo-platonic gardens are being built at the time of Descartes, mechanical museums at the time of Hegel, and, in the late nineteenth century, coincident with Nietzsche and Kierkegaard, we have the profoundly Hegelian march of progress celebrated in the form of the first World's Fairs. All this seems to point to a substantial delay between the critical debate and its institutional acceptance and expression. One must therefore ask what are the implications of twentieth century science for the science museum in the twentieth, and the twenty-first centuries.

The mechanistic and rationalist approach to science that held sway since Descartes has been subjected to several critiques recently, based on the advances in at the turn of the twentieth century, some of the most important coming from within the practice of science itself. These critiques are only now making themselves felt in the design and planning of science museums, and are beginning to change the way in which science is presented to, and perceived by the public.

Based on its historical investigation, and using the insights of late twentieth century philosophy, in particular those of Systems theory, this paper will explore the many directions science education could evolve, and suggests ways in which new directions can be expressed in contemporary science museums, science centres, and in science education in general.

As with any preliminary examination of such a vast and under-researched subject, the paper will be necessarily partial, speculative and occasionally mistaken. For these inevitable failures I apologise in advance, in the hope that the benefits of such a wide-ranging approach will far outweigh the inevitable shortcomings.

Three Generations of Science Centres

For the purposes of this paper I will speak of three different stages in the development of the science museum, according to the approaches taken to the presentation of the nature of science and the artefacts of science.

The First Generation: Imperial Taxonomy

The first generation is likely to be familiar to all, and will need little elucidation. It is the traditional science museum of the late nineteenth century, exemplified by the older parts of the science museum in London, and by the natural history museum in Vienna. In first generation science museums, science is presented as a matter of taxonomy, the correct naming and cataloguing of the world, its animals, its vegetables, its minerals, its principles. All is immutable, unchanging and proven. The rooms devoted to ancient dinosaurs can be safely decorated with friezes of bare-breasted women clutching plesiosaurs without fear of revision, alteration, amplification or amendment. Equally, the principles of electromagnetism can be demonstrated as fixed in perpetuity by Maxwell, perhaps conjured up by a visitors finger on a button, no more, just enough to set in motion the re-enactment of a fundamental truth.

Although these museums were mostly designed in the latter half of the nineteenth century, they were widely emulated, and I am sure that even the youngest of us here can remember being led through the labyrinth of mysterious cases, past the dinosaur skeletons, the dioramas and the steam engines.

The Second Generation: Newton's Hands-on Department Store

In the past two decades, museums have begun to realise that they no longer exercised the same attraction for their audiences, and began to seriously re-examine their approach to the museum experience. Particularly in North America this need to appeal to a broader public was felt acutely.

Coincident with the need to involve a greater spectrum of visitors was the growing conviction that the taxonomic, didactic approach to the material of science was fundamentally flawed, insofar as it denied the viewer any role save that of passive acceptance. Following on the pioneering work in developmental psychology of Piaget and Bruner [2] [3], and on their own research, Richard Gregory and Frank Oppenheimer began work on a fundamentally new approach to the science museum, based on the conviction that learning scientific principles was best accomplished in a multi-sensory, "hands-on" environment, where the visitor was encouraged to participate in a non-trivial was in the re-enactment and rediscovery of scientific principles. From this approach came the San Francisco Exploratorium, housed in the old buildings of the 1919 Pan-Pacific Exposition. [4] [5]

Based on Frank Oppenheimer's principle of the three "i's"; innovation, interaction and involvement, the Exploratorium became the model for a second generation of science museums, and was widely copied throughout North America. Even their names reflected the changed approach. These were no longer science museums, with objects on display, but science centres, Exploratories, even Energeums...

Nevertheless, in the Exploratorium, and in its many imitators regardless of budget, the exhibit structure, and the visitors' experience was still largely determined according to the prevailing scientific disciplines, and the principles presented as discrete demonstrations, stand-alone and self-sufficient, despite the planners initial intention of an "integrative" approach. And, despite an emphasis on perception and illusion,the universality of witnessing was largely taken for granted. In many regards, the new science centres functioned as department stores of scientific principles, where one could wander to and fro from one interactive exhibit to another, looking to be surprised, excited or informed by each one. This particular (in the Newtonian sense) discrete, "sampler" approach is still shared by even the most sophisticated of the second generation science centres such as the Ontario Science Centre or the Chicago Museum of Science and Industry.

Recently several critiques of the second generation science centre have been advanced. While they are superior in nearly every regard in exciting their audience *about* science, there are serious misgivings about the extent to which they are effective in conveying an adequate understanding of scientific principles in anything but the most general terms.

Several recent cognitive tests show that most visitors come to the science museum with a large body of information and misinformation about science, and that the hands-on experience can often reinforce existing mistaken ideas, instead of replacing or modifying them [6]. Clearly there is the visitors' "conceptual inertia" to be taken into account, and the unique and individual character of their witnessing recognised in the design of the exhibits. [7]

However, the way in which second-generation exhibits are designed often precludes interaction among participants, and inadvertently reinforces social stereotypes, such as the knowing father who teaches his son about science, while the passive mother takes care of the little girl [8].

These are all indications of a fundamental attitude, and in many ways the second generation science centre, while addressing the need for participation in the process of science education, married a twentieth century recognition of the importance of interaction to a nineteenth century positivist science, science that described an objective and in many ways unchanging world, un-influenced by the role of the individual viewer and the community of viewers at large.

Accordingly, the overall tendency of the second generation science centre has been to constrain, in many ways, the full participation of the visitor; about the phenomena observed, about the generality of the conclusions, about the way in which the exhibit can be interacted with and about the social interaction itself.

What then would a science museum that embodied the insight of twentieth century science, in other words, a third generation science centre, be like?

The Third Generation: Beyond Hands-on

Many of the sweeping changes in scientific outlook in the twentieth century have focussed attention on the limitations that are placed on our knowledge, by the nature of our observation, by the nature of our ordering, by the nature of the lack of knowledge itself. All of these re-examinations, from Heisenberg to Godel to Poincaré, have had the effect of reintroducing the observer, and the nature of observing, into the doing of science. The mind/body, world/self dualism of Cartesian rationalism has been fundamentally challenged as Einstein's physics swallowed Newton's, Godel's logic swallowed Russell's and Poincare's mathematics swallowed LaPlace's.

In the broadest terms, the twentieth century now demands Heidegger's philosophy (based on Kant, followed by Maturana) [9], just as the nineteenth demanded Comte's. Fundamental to this new outlook is the amplified role of the observer. According to Maturana " The intention of doing science is to explain... and it is in the context of explaining that it must be understood that scientific explanation is the criterion of validation for scientific statements...it must be recognised that a modern scientific community is a community of observers that use the scientific explanation as the criterion of validation." [10] In other words, doing science demands more than haphazard viewing by disinterested observers, doing science demands now, as it did in the seventeenth century, an act of witnessing by observers without bias, who are of equal quality and are committed, deeply and intrinsically to the means, and meaning of witnessing. Science is fundamentally an act of moral commitment. And it is the quality of "generosity" that stems from a science actively seeking consensus, performed by observers acting in good faith that makes it tolerant; a tolerance that does not seek to constrain the conclusions of the participants, but rather serves to encourage their participation.

This has several implications for the development of a third generation science centre, a science centre committed not only to the science of Einstein and Bohr, but to the process of doing science that will ensure it not becoming a fossil record of the ideas of Einstein and Bohr, as their insights too become embedded in a new consensus about the nature of our being-in-the-world.

A third generation science centre would feature the following approaches:

1. Doing Science

Instead of presenting science as a collection of demonstrated principles, science would be presented as an ongoing process in which one could genuinely participate, a process of conversation; of formulating questions, of making hypotheses and finding out ways to test them.

2. Making Connections

Science would be presented as an enquiry, an activity of people questioning in good faith, a way of connecting disparate information, and of recombining approaches to respond to new data and new paradigms.

3. Variety

In a physical sense, a third generation science centre would stress variety and difference; in materials, in scale in levels of explanation, in orientation. Hybrid exhibits capable of recombination and reassembly would become the rule.

4. Coherence

The third generation approach is fundamentally "meta-hands-on". It strives to make every part of the visitor experience, from the moment of their arrival until the moment they step out the door, contribute to a total, integrated understanding of the doing of science as a fundamental human activity.

To briefly recapitulate, the first generation science centres were primarily taxonomic, and attempted to place the world in a one-on-one relationship with its description.

Second generation science centres were a Newtonian insight into the nature of change, like the calculus, second generation exhibits rely on changes over time, principles explained by doing, by re-enactment. Nevertheless, the principle itself remains in many ways an artefact, an intellectual object.

Third generation science centres are second order experiences...the interaction of interaction. Using the model of a dynamic system at all levels, philosophical, moral, scientific, the third generation science centre turns from the issue of demonstration to that of exploration, from product to process. It is the act of making hypotheses and testing them, of not knowing, of observing in good faith and reaching a provisional conclusion.. In this way it is open to continuing revision and change, not only of its own doing, but of the doing of science as well. Third generation science is an attempt to unhook the cart of absolute truth from the horse of enquiry, so visitors can leave not saying "I know", but rather "I know *how* to know".

I will close with two anecdotes, both drawn from my experience with the workers at Richard Gregory's second generation Bristol Exploratory. The drawbacks are outlined by one of the staff, who describes the the way in which children approach the interactive exhibits they discover " First they see a room full of toys and zoom around and play with each of them, then they ask, ' where can I find other things like this?', when we tell them these are the only ones, that they were made specially for the Exploratory, they say 'so what'."

The way forward is described by the Exploratory's workshop manager Rob Knight, whose approach is profoundly in tune with the third generation. He says " I designed an exhibit to explain the various spectra contained in white light, using coloured discs which the kids could spin around on a table until the colours disappeared. This sort of thing can be found at any science centre. But beside the exhibit I put a stack of blank discs and some crayons, with a large sign that said COLOUR YOUR OWN."

The third generation of science centres is about a colour-your-own world, in which the commitment is to a science of processes to be engaged in, not products, processes that can involve adults, children, scientists and laypeople alike in an ongoing discovery of the wonder of the world and our making of it.

Selected References

Blud, L. *Sons and Daughters: Observations on the Way Families Interact During a Visit to the Museum* Unpubl. Abs. (1988) [8]

Borun, M. and Flexer, B. *Planets and Pulleys: Studies of Class Visits to Science Museums* Franklin Institute (1983) [6]

Borun, M. *Measuring the Immeasurable: A Pilot Study of Museum Effectiveness* [7]
Franklin Institute (1977)

Eysenck, M. *A Handbook of Cognitive Psychology*
Erlbaum (1984)

Gregory, R. L. *First -Hand science: the Exploratory in Bristol*
Science and Public Affairs 3 13-24 (1988) [4]

Gregory, R. L. *Hands-On Science: An Introduction to the Bristol Exploratory*
Duckworth (1986) [5]

Hudson, K. *Museums of Influence*
Cambridge (1987)

Maturana, H. *The Biological Foundations of Self Consciousness and the Physical Domain of Existence* (1970) [10]

Piaget, J. and Inhelder B. *Memory and Intelligence*
Basic (1973) [2]

Piaget J. *The Child's Conception of the World* (1967) [3]

Shapin, S. *The House of Experiment in Seventeenth-Century England*
Isis Vol. 79 No. 298 (1988) [1]

Winograd, T. and Flores, F. *Understanding Computers and Cognition*
MIT (1986) [9]

Paradox Lost: Re-discovering Scientific Creativity

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We want to begin by reflecting on two anecdotes from the history of twentieth century science.

The first concerns James Watson and Francis Crick, after they had spent months fruitlessly trying to solve the puzzle of DNA bonding. When the task began to seem unsolvable, Watson spent a spring afternoon mindlessly cutting out stiff cardboard models and gazing at the crocuses outside the Cavendish lab. The next morning the puzzle pairs fell into place. As he later remarked, "Suddenly... all the hydrogen bonds seemed to form naturally..." By lunchtime, Crick was telling everyone within earshot that they had discovered the secret of life.

A second story concerns Einstein and the Theory of Special Relativity. The Times of London called it "an affront to common sense" and so it was. The theory overturned our ideas of space and time to underpin the most successful predictive paradigm in the history of science. Einstein attributed his discoveries to what he called his fantasy, his capacity to move outside the boundaries of contemporary thought or observation. "It is a magnificent feeling," he said, "to recognize the unity of a complex of phenomena which appear to be things quite apart from direct visible truth."

These anecdotes describe intellectual processes that are fundamental to the development of science - imagination, intuition, and the ability to find a coherent explanation for widely divergent phenomena. These skills are the essence of scientific creativity, and they have fuelled the progress of science for centuries. Yet only rarely are they to be found within the walls of the contemporary science centre.

Let us look for a moment at the kinds of exhibits that we do find on display at our museums and science centres.

First, many of our exhibits communicate principles, not processes. These exhibits are a physics text in three dimensions. They encourage visitors to think in terms of a canonical hierarchy of scientific laws. Each of these exhibits represents a single experiment, which inevitably ends with the same result. The least instructive of these exhibits are automata in which the visitor participates by pressing a button. Presto - science happens. The result, all too often, is that the visitor has no intellectual engagement with the subject matter. The exhibit is whole, complete unto itself, science under glass.

Secondly, many of our exhibits fail to communicate the structure of scientific thought. These exhibits focus on conclusions, devoid of process, as if results leapt *sui generis* into the scientific mind. Our visitors never see the false leads, the disillusion, the failures. These exhibits misinform the public of the true nature of the scientific enterprise, making it seem as though there is a simple one-to-one relationship between hypothesis and result.

Thirdly, our science exhibits tend to treat the science as a series of discrete breakthroughs, unique events in time. This approach denies the continuity of scientific thought through history, and masks the links between science and technology. Take the Bernouilli Blower for example. No respectable science centre would be without one. Everyone loves the beach ball bouncing cheerfully on a jet of air. Yet, very few visitors understand the technological implications of the principle it demonstrates. It is true that some museums have mounted a model of a 747 next to the beachball, but I dare you to find more than one visitor in a thousand who understands the connection between the two.

Finally, our science exhibits put the visitor in the role of receiver, rather than generator, of scientific thought. The visitors participate, to be sure. They push, pull, blow and bellow, but only rarely do they actually investigate a question that is of personal interest to them. The underlying message to the public is that only scientists can define the subject matter of science. This deprives our visitors of the chance to participate in the most dramatic and satisfying aspect of scientific behaviour - the opportunity to pinpoint a paradox and hazard an explanation.

Now none of this would matter if science centres were like movies or ice hockey games - a simple form of entertainment. But science centres have claimed a higher goal, and they have claimed it publicly: to educate as well as to entertain. The statistics that have emerged in recent years, describing evaluations done in interactive science centres around North America, are not encouraging in this regard. The data shows that visitors spend very little time at many of our exhibits, and that they rarely read the text. Many of our visitors cannot describe the scientific principles that underlie the exhibits that they have just enjoyed. Exhibition halls full of interactive exhibits produce the notorious "pinball" behavioir, in which children become whirling dervishes darting from exhibit to exhibit.

Exhibition planners have devised a number of clever - and untestable - excuses to explain the supposed success of our exhibits. We say that the exhibits help to break down our visitors' deep wariness of everything scientific. We argue that that our visitors will carry away a subliminal scientific message which will somehow magically leap to the fore in later years. In our view, all of this is simply papering over the cracks of a design philosophy and an exhibit technology that is not adequate to the task. If we fail to engage our visitor's minds, if we have developed exhibits that are no more intellectually challenging than arcade games, we cannot expect a upsurge in scientific understanding.

So what kind of exhibits should we be producing? It is the position of this paper that the fundamental skills scientific literacy are imagination, extrapolation and a sensitivity to scientific process . Moreover, we believe that it is the responsibility of our science centres to develop exhibits that allow the public to experience these creative forms of thought.

To explore this idea, we can make a loose analogy between science literacy and verbal literacy. Students who are learning to read do not just learn an alphabet. They do not only learn a vocabulary of primary words. Rather, they learn to use the alphabet and the vocabulary as tools, so that they can decipher new words at will. Reading empowers us to discover for ourselves.

In a similar way, we must give people the tools to think scientifically.
Why is this task so important? We would suggest that there are two reasons. In the first place, it is becoming increasingly clear that our young people have problems when they are asked to think scientifically. Interviews we conducted with education staff at a Canadian science centre indicated that the most popular outreach activity of the school year takes place during the weeks when students are required to develop projects for the local science fair. These students, many of whom do very well in courses where they are expected to memorize scientific facts, are unable to formulate a scientific question or

to develop a process for testing it. The educators say that when these students arrive at the science centre they are often paralyzed, unable to think in the face of a question for which there is no "correct" or known answer.

Secondly, we feel it is important to give our adult audiences the opportunity to develop a critical attitude toward scientists and the scientific information that is in the public sphere. Only as people learn that science is based on premises, and that these premises can be questioned, can we hope to create a society in which a dialogue takes place between scientists and the public at large. Science literacy, seen as seen as a set of skills rather than a bank of knowledge, empowers us to meet the challenges of a technological society.

So how can we draw the process of scientific thinking into our science museums and science centres? What are the hallmarks of exhibits that encourage the public to grapple with questions of scientific content? We would like to develop a number of examples, some of them currently in existence, others merely the products of our imaginations.

1. Exhibits that encourage scientific process.

One of the leading institutions to have tackled this problem is Science North, located in the hard rock mining community of Sudbury, Ontario. At its inception, it was decided to develop the exhibition space as a series of laboratories dedicated to specific fields of science; so there is a Geology lab, a Zoology lab, a Human Performance lab, and so on. Each of the labs is fitted with a variety of professional lab equipment around which the visitors are invited to devise their own experiments.

The success of this programme depends on a few fundamental features of the design. First, there is a high ratio of staff to visitors. Staff members are trained to help visitors develop their questions into testable hypotheses. Secondly, visitors are not provided with instructions about how to do experiments. Indeed, for the first five years of the centre's existence, the laboratories did not contain more than a few words of text. This proved to be somewhat unwieldy - some visitors couldn't for the life of them think of a question - so the centre now provides a notebook with some suggested places to start. Nevertheless, this is a long way from the high school classroom, and a long way from the 3-D physics textbook we referred to earlier.

The result is an extraordinary process-oriented exhibition space, in which visitors may spend an hour or more in a single lab. There is a high degree of interaction among the visitors, and the debate is lively. The results of experiments can be unpredictable. Last time I was there I observed a group devising an experiment to test the lung capacity of the smokers and non-smokers in the family. To the chagrin of the non-smokers, the experiment showed that the smoking tennis players were fitter than the non-smokers whose hobbies were watching television and eating popcorn. I have every reason to believe that the non smokers are still debating possible flaws in the methodology every time there is a family reunion.

2. Exhibits that encourage problem solving

A few years ago we conducted an experiment that looked at the way visitors at a science centre approached the solving of topological puzzles. The circumstances of the puzzle table, I should point out, were ideal. It provided a place to sit, in a quiet space that was away from active exhibit areas. To our surprise, we found that visitors were inclined to spend long periods of time concentrating very intensely on how to solve the puzzles. Moreover, as we listened to conversations at the table, as visitors made suggestions to one another, it became clear that people were attempting to solve the puzzles by building three dimensional intellectual models and then testing them.

We have also been very impressed by the series of games developed by England's Wondersmith, Francis Evans of Sheffield. At first glance, they seem to be no more than a pile of tumbledown bridges, blocks, weights and balances. But by the time the structure is complete, visitors have confronted and overcome a series of problems. The marvel of these exhibits is that visitors must formulate a problem before it can be solved. And yet the games are as accessible to small children as they are to adults. And, wonder of wonders, they are enormously appealing to girls and women.

Nor need we be limited to designing exhibits that can be manipulated by hand. For example, we might create a computer game in which the visitor takes the role of a petroleum geologist who must decide where to drill his last hole before his money runs out. The educational objective of this game is twofold: it requires that the visitor develop a logical process for gathering information, and then to create a three-dimensional conceptual image of the underground structure.

Using a combination of real specimens and computer-generated images, the visitor would examine the results taken by geologists from an existing oilfield. What do the core samples tell us about the porosity of the rock in different parts of the field? What kind of pattern can be produced by analysing the two-dimensional seismic records to produce a three-dimensional image of the underground structure? And then, where do you drill?

3. Exhibits that encourage extrapolation

Some people are inclined to be sceptical at the idea that the public can solve problems outside the strictures of accepted paradigms. Their idea is that only an Einstein or a Feynman can link a mass of conflicting evidence by taking a brilliant lateral leap.

We would like to take exception to this idea. We believe that these thought processes are more common in every day life than one might think. One area in which the public participates, with great avidity, in finding these kinds of solutions is in solving murder mysteries....whodunits. We suggest that the best of this genre ask readers to weigh the weaknesses and strengths of several well-crafted arguments. They require a mind that is sceptical, that seeks solutions beyond the obvious.

While the traditionalists among you shudder, let us draw your attention to the often paraphrased passage in which Sherlock Holmes says to Watson, "The clue is in the barking dog."

"But there was no barking dog.", replied Watson.

"Precisely."

In our view Holmes' insight bears a remarkable similarity to such cosmological conjectures as black holes, which can only be inferred from the absence of electromagnetic radiation. So why do we not create science exhibitions that encourage visitors to make a Holmesian, or Hawkingsian, intuitive leap?

There are myriad ways in which this thinking might be embedded in the exhibit process. The annals of medicine, for instance, are filled with encounters that depended on both rigorous logic and brilliant insight. Thus we might create an exhibit that encourages visitors to take the role of a doctor, examining a patient who shows symptoms of a mysterious disease, perhaps causing him to develop zebra-like stripes across his body.

Certainly the cataloguing of symptoms calls upon the visitor's skills of analysis, however the final pinpointing of the causes of the disease may rely on asking questions that lie outside the normal medical frame of reference. Exhibits that can capture this process would allow our visitors to experience one of science's greatest satisfactions: the flash of insight, the successful intuitive leap.

In conclusion, we must say that exhibits such as these will only be successful if visitors understand that they are being challenged to develop new thinking skills. We cannot pretend that these skills are entertainment, that they can be captured without intellectual effort. We do not expect people to learn them unconsciously, nor can we expect them to learn the skills of science unconsciously either.

Still, while our exhibits may not be entertainment, they can be entertaining. The can communicate the great joy that scientific thought brings. The greatest gift we can give our young people is the ability to employ at will the tools of a creative imagination, tools that take them to the heart of the scientific endeavour.

Fields of Knowledge:
Harvesting Scientific Understanding

a paper delivered at
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as Science des villes, science des champs

Just over one year ago, the Science Museum in London hosted a conference on the Policies and Publics for the Understanding of Science and Technology. Participants came from all over the world, and the debate was informed, thoughtful, and restrained. Beyond the restraint, however, a fundamental contradiction that hovered over the delegates.

Ranged on one side was a group of international scholars responsible for what have been called scientific literacy studies. These studies share one point of departure: they seek to define the level of scientific literacy among the general public. In most of these studies, scientific literacy is defined by three measures.

1) The subject must know the correct answer to a group of questions stemming, in the main, from the disciplines of physics, chemistry, geology and biology;

2) the subject must answer a group of questions about the scientific process; and

3) in some cases, the subject must answer questions about the ways science and technology have an impact on everyday life.

This general methodology was followed, with roughly the same questions, in studies in Canada, the United States, Britain, France and Japan. And everywhere the results made headlines. It was discovered, with some shock, that only 5.6% of American adults and 7.1% of British citizens met all of the criteria for scientific literacy. All over the Western world, reviewers recoiled from the inevitable conclusion: "Good Lord, we are a nation of idiots!"

Let us examine the beliefs of the science literacy school more closely. The enthusiasts make two assumptions. In the first place they assume that science is a consistent body of information which can be held to be universally true. Thus Durant et al have written "Science is an enormous and enormously complex body of knowledge. Much of this knowledge is essentially unproblematic, in the sense that all competent experts agree about it..."

From this immense body of scientific knowledge, the science literacy experts extract certain facts that they identify as fundamental to the thinking of any informed citizen, and these facts become an intellectual yardstick by which the people of any nation can be measured. "We wish to discover how much science people know, and how far their beliefs may differ from formal or official science.", writes Durant. "In neither case do we see how this can be done without forming some estimate of people's understanding against the bench-mark of science itself."

The universal standard can be a harsh judge of the public understanding of science. Like the stern schoolmasters of old, it delivers only a pass/fail verdict. There are no extra marks for creativity. There are no indulgent smiles for a keen grasp of, for example, Early Cretaceous invertebrate palaeontology. For the science literacy specialists, to fail the test is to fall below the minimum standard of a scientifically aware citizen. One of the leading exponents of this approach, Jon Miller of the Public Opinion Laboratory at Northern Illinois University, commented, "I doubt that anyone would argue that a citizen who failed the minimal set of items included in this measure would be very effective in following major issues in science and technology."

However, some of the scholars at the London conference did argue just that. Dr. Brian Wynne, the Director of the Centre for Science Studies and Science Policy at the University of Lancaster, set out a body of data that was sharply at odds with the science literacy school. Dr. Wynne and his team of researchers had interviewed sheep farmers in the Cumbrian highlands after their farms were closed in the wake of the disaster at Chernobyl.

They found that the farmers possessed a great deal of scientific information about issues in their own realm of experience, such as the science and economics of sheep farming. Moreover, this expertise was sometimes at odds with the advice of the government appointed scientists who were sent out to 'enlighten' them. Dr. Wynne's evidence indicated that the scientific approach of the sheep farmers may be "less generally authoritative, but was more specifically accurate" than the information of the government scientists.

At the end of his study, Dr. Wynne concluded that members of the public do not experience scientific information separate from the knowledge or expertise they have in other areas of their lives. Quite the opposite, they actively blend old and new information to construct a fresh scientific understanding. To describe this process, we might make use of the metaphor of uncorking a bottle of champagne. Like carbon dioxide dissolved in the bubbly, the scientific understanding of members of the public is invisible - until the moment that the knowledge is required to cope with a set of real life experiences. In the case of the Cumbrian sheep farmers, their understanding of the science of sheep farming and nuclear physics came to a head when the disaster at Chernobyl forced the closure of their farms.

Underlying the work of Dr. Wynne and his colleagues is an assumption about the nature of scientific understanding that is sharply at odds with the views of the science literacy school. Dr. Wynne describes scientific understanding as both circumstantial and social.

The implication of this view is that a scientifically literate society seeks citizens who can make reasoned and intelligent decisions by weighing a variety of factors. Some of these factors are scientific and technical, others may be social, economic or political. A conclusion that holds in one set of circumstances may be invalid in another place at another point in time. Thus, the validity of any particular conclusion cannot be measured on a single scale. This suggests that the conclusions of science may be universal, but scientific understanding is not. The public understanding of science is complex and mutable: changeable and changing.

And so, throughout the London conference, scholars debated two sharply conflicting ideas of the public and its understanding of science. In the view of the science literacy school, the public is passive, often unable to capture the body of scientific information required to construct an intelligent opinion about issues. The other view suggests that average citizens are able to grasp, build and manipulate complex ideas - especially when they pertain to a subject that is important to their own survival, or the survival of their community.

Now this debate is not merely an academic argument, to be hung out on the clothesline every time an international conference is held. On the contrary these assumptions are critical because they affect the course of action that is to be taken to produce a broader public understanding of scientific issues.

If the science literacy school is correct, and there are certain facts that must be understood in order to produce a population comfortable with science, then we must develop programmes that will diffuse this knowledge more effectively throughout the population. And by and large, this process of diffusion must take place from the top down. The haves must provide to the have-nots.

If, however, we believe that our citizens are already equipped with ideas and information, curiosity and skills, then our goal must be to enhance and encourage their experiences. We must find ways to uncork the champagne, so that people explore and share the ideas that are already important to them. This is, by its nature, a grassroots process, in which the energy explodes from the bottom up. The public determines the topics that should be explored. The public charts the direction of the exploration.

So much for theory, what about practice? For the last two years, we have had the opportunity to work as consultants on a project designed to increase the public understanding of science in the province of Alberta, in Western Canada. Before we describe our work, let us digress for a moment to tell you about the Science Alberta Foundation and its mission.

Of all of the provinces of Canada, Alberta has a particularly strong background in the fields of science and technology. It is the home of Canada's oil industry and thus has the highest proportion of geologists and engineers in Canada. The City of Calgary, moreover, has the highest per capita income in the country, a reflection of the benefits that have accrued from oil and gas in this energy-conscious era.

But Albertans are aware that this boom will not last forever; the province's energy resources are now declining. If we are to survive, new economic generators that will have to be found to sustain the province through the next century. No one is more aware of this than James Gray, the Executive Vice President of one of Canada's most innovative, home-grown oil and gas companies. In 1989, Mr. Gray announced the formation of the Science Alberta Foundation, with the mandate to raise the level of public understanding of science and to encourage more young people to consider careers in science and technology.

In the beginning, the Foundation's emphasis was on building a network of new facilities for communicating science information. In his opening speech, Jim Gray announced:

"We can build an integrated network of science centres. We can build large centres in the cities of Calgary and Edmonton, and satellite centres in Northern and Southern Alberta. We can exchange exhibits, construct joint exhibits, book lecturers and scientists. We can deliver exhibits and programmes to small communities in rural Alberta."

This was, by definition, a top-down idea that shared some of the assumptions of the science literacy school. The large urban museums and science centres would develop travelling exhibitions and circulate them through smaller communities in the province, thereby introducing all Albertans to new ideas in science and technology. The network was to be centralized and dependent on the skills of a small group of professionals who would select the relevant science information and prepare for an audience of non-scientists. At the time, none of us imagined how dramatically our ideas would change.

The first surprises came as the result of a survey that we conducted to help us to evaluate the audience for the science programmes that would be shipped around Alberta. In conjunction with the Coopers and Lybrand Consulting Group, we designed a telephone survey destined to reach almost a thousand Albertan homes. Our questions were designed to evaluate what science subjects Albertans find interesting, and to identify the science-related activities Albertans engage in, and with whom.

As soon as we made the first cut of the data, it was evident that we were not looking at an audience that was unified either in terms of interests or behaviour. The profiles of our four basic audience groups - rural men, rural women, urban men and urban women - suggested that each segment was going to make very different demands on our science network.

Let us briefly cite some of the results. Both urban and rural men show a high interest in science, and particularly in the pure and applied sciences. Physics, chemistry, engineering and computer science get a high positive response. Men, and particularly urban men, are the least interested in medicine and biology. Women on the other hand, in both urban and rural areas, tally a high interest in biology, medicine and the environmental and social sciences. In the hard and applied sciences, however, women show considerably less interest.

This data suggested to us that both men and women in Alberta are enthusiastic about science, but they frame their enthusiasm in markedly different ways. Indeed, when we looked at the overall results for men and women, their responses were so distinct that we wondered how an Alberta marriage stays together. What do they talk about over dinner?

Similarly, there were marked differences between our urban and rural audiences, consistent with Brian Wynne's suggestion that people develop an interest in science subjects that affect their social, political and economic lives. Albertans living in rural areas show much greater interest in subjects like agriculture, forestry, conservation — and the weather.

By the time we concluded our survey, it was becoming clear to us that we could not create the top-down, centralized science network that we had originally outlined. We could not treat all Albertans as an undifferentiated mass. What was interesting to one Albertan was clearly dead boring to his neighbour — or his wife. Moreover, the differences between rural and urban Albertans would make it impossible to develop exhibits in the city and send them off to be appreciated by farm families. Scientists may see science as a consistent body of verifiable knowledge, but the public sees science as a smorgasbord, to be sampled according to one's own inclinations.

Our database received dramatic confirmation when we visited communities throughout the province to test the concept of a science network. Everyone we spoke to - town councils, womens' organizations, student groups - used the opportunity to tell us that their concept of a science network was very different from our own.

Let us take a moment to tell you about our meeting in Drumheller, a town of three thousand that lies over an hour from the nearest large city. There we met with a group of citizens representing a broad spectrum of civic organizations, both scientific and non-scientific. They told us in no uncertain terms that the concept of a top-down network based in the cities would not meet their needs. They had one point to make, and it was a political one: The people of Alberta want to be generators, not receivers, of scientific education. They want to decide what ideas should be communicated and how they should be communicated.

To prove their point the took us out into the harsh and exquisite terrain of the Western badlands, showing us how the dramatic stratigraphy forms a timeline through millions of years of geological history. We visited the magnificent bonebeds where paleontologists are piecing together the flora and fauna of the Cretaceous period. We scrabbled down into abandoned coal mines and tramped over terrain that illustrated seven separate ecological regimes in as many miles. And we were convinced: the people of Drumheller had their own unique science story to tell.

On our return to the city, the Board of the Science Alberta Foundation reviewed our data, and made three decisions that stood the original concept of a centralized, top-down science network on its head.

1. First, the Board *decentralized* the political control of the network. Board members abandoned the notion of a network based in one or two cities, and began to encourage the development of small, regional science councils run by local enthusiasts. The first of these councils was set up in the district of Vulcan, where five farm villages banded together.

2. Secondly, the Board *deinstitutionalized* the network. Rather than using its funds to establish a network of museums and science centres, the Foundation decided to make a large proportion of its funds available to community organizations, so that they could develop exhibits and programmes to meet the needs and interests of local people. Correspondingly, the emphasis has shifted from constructing a few large buildings to using left-over space in existing buildings all over the province: the corner of a public library, an empty storefront, even, in one case, an abandoned aircraft hangar.

3. Finally, the Foundation *deprofessionalised* the network. The Board dispensed with the assumption that only experienced scientists, science educators and exhibit designers could create the high quality materials that a provincial network would require, and began to actively develop programmes that will allow citizens from every walk of life to build science exhibits and programmes.

Overnight, the emphasis shifted from top-down, to bottom-up. In effect, the Foundation threw down the gauntlet: if the communities insisted that they were able to develop public science programmes as well as the professionals, they would have the opportunity to prove it.

Now, to be frank, the idea of a grassroots movement for science education caused some consternation in the museum and science centre community. Even we occasionally worried that we were theorizing our way out of the most interesting work we had ever had. But there were no such concerns at the community level, where individuals and groups organized themselves to take advantage of the Science Alberta Foundation's programmes. We would like to take a few moments to discuss some of the most unusual and exciting of these initiatives.

1. The Matchbox Science programme challenges every child enrolled in junior high school in Alberta to develop a science experiment or exhibit that can fit into a matchbox. To date, a number of young people have developed interesting solutions to the problem. One young person put an egg in the box, with instructions to squeeze the egg as hard as possible. Why doesn't it break? It is a simple experiment, and vastly cheaper than most of our professionally-designed exhibits.

At the end of the year, the top forty Matchbox experiments will be cloned and distributed to schools and libraries throughout Alberta, the first step in what we hope will be a provincial hands-on science collection. In effect, the young people of the province are becoming experienced exhibit designers, responsible for communicating what they have learned to future generations.

2. The Science-In-The Streets programme offers grants of up to $10,000 for the development of interpretive programmes that use the unique resources of a region of the province. This programme has stimulated a wide range of responses. In the west, a group of retired coal miners are reopening an abandoned coal mine, so that they can explain hard rock mining technology to young people. In the east, a group of farming villages have banded together to put on a science summer festival. In addition to demonstrations and displays, each participating family will be given two weeks to solve a scientific challenge. One of the rules states that every team must include one person under the age of five.

The importance of these initiatives is twofold. First, by requiring communities to use existing resources and local volunteers, the programme encourages self-reliance. Science education is not something you import, it is something you create. Secondly, by forcing communities to set their own priorities, the grants stimulate co-operation between organizations. Recently, three rival environmental organizations submitted a joint proposal for a nature walk that will link to the community school.

3. The Networks Programme offers up to $50,000 for the development of innovative approaches to a province-wide science network. These grants are a challenge, because they force communities to think of opportunities that will benefit not only the immediate

area, but the people of the province as a whole. In the far north, for example, where one community can lie hundreds of miles from the next, ten small towns have banded together to build a mobile science laboratory that will travel to schools, industries and wilderness parks. This is a flexible facility that will allow each community to investigate science subjects that are pertinent to its surroundings.

Another initiative: the farm wives of Alberta have created a network of ranches and farms that will educate city children about life on the modern farm. And this goes beyond petting geese. The city kids are expected to tramp through the fields running experiments on soil conservation, pesticide control and water quality. These farm wives want to foster a new appreciation of the complexities - scientific, technological and economic - of high tech farming at the end of the twentieth century.

And what about the citizens of Drumheller? They have designed a science summer camp. Young people will be bussed in from all over Alberta to spend a week studying the geology, palaeontology and ecology of the badlands. And in their usual feisty way, the people of Drumheller informed the Science Alberta that if they do not receive Foundation funding for their idea, they intend to build the camp anyway.

From our perspective, there is one startling aspect to these projects. They are unique to their time and place. Not one is the kind of educational experience you would see in an urban science centre. Not one community, for example, found itself in desperate need of a Bernouilli Blower or a Van der Graaf generator.

Instead, these programmes pose "real life" questions. Unfailingly, they integrate several scientific disciplines, they pose dilemmas that are economic and political. Community people may not be interested in the raw facts of science, but they are acutely interested in the way science meshes with their everyday lives.

So what have we learned in a year and a half?

First, we have learned that people have widely differing interests in science and technology depending on their gender and the region in which they live. These differences must taken into account as part of any programme for delivering scientific and technological information.

Secondly, we have learned that experience gives people an authentic and legitimate understanding of particular domains in the realm of science. This experience should be recognised and encouraged as the foundation of an enriched scientific and technological culture.

At the present time we are exploring ways to take this idea one step further, to examine if people learn best when knowledge is embedded in a context is relevant to their experience. We believe that the appropriate context may demonstrate an active ability to exercise the skills we normally associate with a scientific approach: abstract thinking, deduction from hypotheses, and the testing of alternatives.

Finally, our experience in Alberta has raised questions that are profoundly political in nature. To discuss scientific knowledge is to raise the issue of who has the right to produce this knowledge. The science literacy school suggests that the path to scientific knowledge is the official one of schoolrooms, universities and laboratories, and that only the elect, clad in the lab coats that are the alb and chasuble of the ordained scientist, have the right to affirm scientific knowledge.

The Alberta experience, on the other hand, suggests that there are other paths to scientific knowledge, that people absorb scientific information through their work and their neighbourhood. The people of Alberta would assert that this knowledge gives them the right, even the duty, to become full-fledged partners in the communication of science.