# The Exploratory Interactive Science Centre

# Plan for Action 2, February 1985

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## SUMMARY

### What is an Exploratory?

The EXPLORATORY is to attract and introduce people to principles of science and technology. Its impetus is the perhaps strange fact that only very few people understand, and fewer use, the methods of science for evaluating evidence or appreciate the living symbiosis of science and technology which has created our world.

The EXPLORATORY will be an exciting place where children and adults can explore the world of Science and Technology hands-on, with a variety of working exhibits, simple experiments and puzzles and games of many kinds – which will not only illustrate but reveal, sometimes in depth, phenomena of nature and the explanations of Science and its results in Technology. Some of the experiments and demonstrations will also allow one to find out quite a lot about oneself. Unlike the exhibits of a conventional museum, these are not just to be looked at – but to be used. For this reason, we call the exhibits 'Plores' – to be explored. The EXPLORATORY will be 'interactive', and not passive as are conventional museums. The visitors (the Explorers) will themselves take an active part, generating their own interest and enlightenment, as – like the activity of science itself – they play games against nature, end sometimes win.

Sections of this document describe in detail the aims and philosophy, the content and methods and the administration of the EXPLORATORY which now seeks substantial support, to be the effective pioneer in a development which promises to have major significance in this country.

### The Origin of the Project.

The project is based on the highly successful Exploratorium, founded over fifteen years ago by the late Frank Oppenheimer, in San Francisco. The Exploratorium has inspired several interactive Science Centres in the United States and Canada: the EXPLORATORY will be the first hands-on Science Centre, together with the London Science Museum's Launch Pad gallery, in Britain.

The EXPLORATORY is the idea of Richard Gregory, head of the Brain and Perception Laboratory at the University of Bristol. Professor Gregory is well known for his work in the fields of visual perception and artificial intelligence, and also as one as the most efiective presenters of science to a general audience. (He gave the Royal Institution Christmas Lectures in 1967-8, and has written several well-known books, including 'Eye and Brain', 'The Intelligent Eye', and 'Mind in Science'.) The nature of individual perception and understanding is an ideal subject for interactive methods and will be a central theme of the EXPLORATORY.

### Initial Funding

The initiation of the project was made possible with a grant from the Nuffield Foundation.

This financed a feasibility study, which was carried out in 1980. The Nuffield Foundation then provided a second grant, and with further support from the Carnegie Trust and one of the Sainsbury family Trusts, we were able to employ a Project Manager, an Administrator and several people on an ad hoc basis, to build about fifty Plores, initially for the three exhibitions that we have presented. This funding has also allowed us to rent premises for a workshop and administrative offices.

## The Organisation.

The EXPLORATORY is a company limited by guarantee and has charitable status. It has a board of Trustees, who are advised by a distinguished Scientific Committee. This has recently been augmented by a Management Committee, which includes members with experience in financial matters and scientists and educationalists. The membership of the Trustees and the other Committees may be found in Appendix 6.

The centre of operations is a workshop, offices and a small Visitor Centre (3,000 sq. ft.) at 131 Duckmoor Road, Ashton Gate, Bristol. At present the staff is the Project Manager, Steve Pizzey, and Kate Tiffin who is the Administrator.

## Exhibitions and Events

The Exploratory has been the subject of a number of press, radio and television features – starting from its first public demonstration at the annual British Association conference at the University of East Anglia in the summer of 1984. A collection of fifty or so 'Plores', which we designed and built, was on display and available for exploring for the five days of the British Association. This event received an enthusiastic response from the visitors, who ranged from school children to professional scientists, including at least two Nobel Prize winners. Since then two events in Bristol for non-scientific visitors – The Children's Festival October 1984, and an Exhibition at Watershed Multi-Media Centre in the City docks – have been received just as enthusiastically.

We learned a lot from a most successful Mathematical Weekend, at which thirty well known mathematicians shared their ideas for making mathematics understandable with working models, computer graphics, games and in other ways which we intend to develop.

## The Immediate Aims and Development Strategy

From the outset the project has had the co-operation and support of the Bristol City Council. Through its good offices the EXPLORATORY has the opportunity to make its final home in 'C' Bond Warehouse – a large and magnificent building in the Cumberland Basin area of Bristol, on the river in the harbour. This option was set out in a previous report- Plan for Action – One (1983) and it remains a long-term aim to take this building over and adapt it. This is a very ambitious project – which cannot be undertaken without setting up a consortium of related activities and with an input from industry. Should this prove practicable, it will take at least three years. The Trustees are, however, anxious that the project should maintain its present momentum, and avoid losing the interest and goodwill that has been generated. The Trustees have, therefore, decided to plan the opening of the Exploratory in a less ambitious way: in about 10,000 sq, ft. in a remarkably suitable building, which has only recently become available – the historic broad-gauge engine shed of Isambard Kingdom Brunel's Great Western Railway terminus of Temple Meads. Brunel's drawing office floor has been offered to us, on a short-term basis of 2-3 years, by the Brunel Engineering Trust. Our initial – once only – contribution will be £20,000. We will not have to pay for the repair or conversion of the premises, which are currently under way for the Brunel Engineering Trust. This seems, in every way, an ideal arrangement for starting the EXPLORATORY. Our Project Manager, Steve Pizzey, has done a first class job negotiating this arrangement. The estimated cost of getting the EXPLORATORY running at Temple Heads is a total of £370,000. A detailed description of the plans for opening the EXPLORATORY at Temple Meads are given immediately below in Section 3.

It is our firm intention that the EXPLORATORY will be self-supporting once established. We believe that it can cover its running costs from entrance charges and additional revenue generated by the shop and by events. The reasoning behind this belief is also given in Section 3 below.

## The General Aims and Philosophy of the EXPLORATORY

Later appendices describe the background and aims of the project and give details – with captions and drawings – of the interactive exhibits ('Plores' for exploring) of the first British Association Exhibition exhibition. These represent the heart of the EXPLORATORY as it is now conceived and built. Here are pendulums and conic sections, gyroscopes and games with gravity, as well as illusions to remind us of our fallibilities.

Other Appendices discuss the working philosophy, and the interesting and by no means solved problems of how to present information and provide appropriate help for exploring for the wide age and education range of our visitors. Above all, the EXPLORATORY will be an enjoyable experience, and a stimulating introduction for understanding Science and Technology and appreciating what they have to offer, now and in the future. This must be achieved without intimidating people who have not (at least before their first visit I) seen what makes science interesting – and how its principles live all around us, unseen in our every-day technology.

## Authorship

Although sections of this document have of necessity – because they cover very different technical matters from finance to philosophy – been written by different hands (and we trust brains), the document represents the collective aims and ideas of the EXPLORATORY Trustees and Managers, who have discussed it in detail and have contributed in very many substantial ways. The authorships (indicated with initials referring to the author list on the index page) are individual responsibilities, according to special knowledge and interest, within the collective wisdom of the EXPLORATORY's Trustees and Managers, who have taken on and accept shared responsibility for guiding this project with imagination and responsibility.

R.L.G.

## INTRODUCTION TO THE EXPLORATORY

### Background

Science and technology have throughout history gone hand in hand, raising us from our biological origins to made man a unique species, with a life and a culture of his own which has no parallel in nature. Whatever their shortcomings, science linked with technology are the most successful of all co-operative human endeavours. Their discoveries and inventions are incomparably useful (though unless we understand them, correspondingly dangerous) and they arc uniquely intellectually satisfying – while always leading to new questions and further possibilities. But for too many people, surely, science and technology are remote and even hostile, perhaps because they seem too difficult even to begin to understand. We believe that the facts and fancies of Science can be made accessible to most people – children and adults – and that the best way to do this is by exploring for oneself; with help, a minimum of hassle, and a lot of excitement and fun which will bc found in the EXPLORATORY.

The EXPLORATORY is to attract and introduce people to principles of science and technology. One might ask – is this necessary? It is, for most people are blind to the explanations that science offers and do not appreciate how even their own possessions work. For example only very people can answer questions such as: 'What is an electron? – a Proton – a Molecule?' Or, 'What holds the Moon up?' 'Why is the sky blue – and why are bubbles coloured?' 'How long does light take to reach us from the sun? – From the most distant object visible to the naked eye (2,000,000 years)? Or 'What is 'Natural Selection'' Or 'How are ball bearings made accurately spherical’?' 'Why are we right-left reversed in a mirror?' 'Why is a refrigerator cold – and a flame hot?'

Although few educated people can answer such questions, or use the methods of science for evaluating evidence, there is general agreement that this is unfortunate. A recent Gallup Poll (published in New Scientist, 21st. Feb. 1985) reports that 86% of the general population thinks that, 'Everyone should have some science education up the age of 16’; and 76% that, 'Politicians should know more about science and its applications.' It seems, however, that there is considerable fear of science, for even apart from military applications, 73% think that, 'Scientific discoveries can have very dangerous effects.' And opinion on whether 'science and technology do more harm than good' is about equally divided.

Undoubtedly science is dangerous; but so is lack of it, and so is ignorance. Here everybody loses, and administrators lacking appreciation of technical issues can lose their way, to run into dangers of losing their firms and the rest of us an awful lot of money, and perhaps worse disaster. And 'merely' academically' – the culture in which we live becomes distorted unless the contributions of science and technology are appreciated. Much of recorded history is distorted by 'filtering out' technology and its effects, as happens for many historians are blind to their significance; even though science and technology are ratchets, producing hopefully 'upward' irreversible changes. By contrast, most of recorded history is more-or-less random movements across essentially arbitrary political borders, yet this claims far more attention than the human-long dramatic saga of discovery and invention.

Even stranger: most of us, as adults, cannot answer the simplest questions of science, or of how things work, though children continually experiment, while playing. They learn a wonderful lot in a very few years including, most miraculously, language. But generally this learning slows and almost stops at adolescence, when for many people curiosity is dulled. Why this is so is mysterious – and of course it doe not apply to everyone. How many of us, though, know how the most familiar for gadgets work? For example, how their front door key turns the lock – and only with their key and not thousands of others looking almost the same. Ways of making locks recognise particular keys is a technology known to the Romans; yet few of us appreciate how locks and keys work, though we use them every day, which is surely a pity as mechanisms are much more than bits-and-pieces of metal: they embody principles of nature combined by human intelligence to solve our problems. Largely unnoticed, they are our richest inheritance.

If we know how to look we can see – for example in a humble lock and key – not only mechanical processes of bearings, levers and stops but also more abstract principles, such as general statistical principles, which apply to the courtship behaviour of birds (and perhaps people) and to the immune system (which goes wrong with AIDS), as well as the immensely difficult pattern-recognition problem that, though we are unaware of it, confronts the eye every moment of the day. Then, in a device such as a lock, there are all sorts of manufacturing solutions such dimensional tolerances; for if the key were a precise fit it would never work, as it expands with the heat of one's pocket, and the critical parts wear gust slightly every time it is used.

So, in this one example it is possible to see a wealth of design principles as laws of physics, and of statistics, all brought together in a simple mass-produced package which is designed to fill a human need. But to see how it works, it may be is necessary to open the lock and play with it, and take it to pieces. This is the essential point of the hands-on interactive approach to presenting science and technology in the EXPLORATORY – to continue children's exploration of the world and themselves into adult life so that the adventure of discovering never ceases.

There is plenty of evidence that our abilities to see and understand – which are closely linked – develop from infancy by actively handling and interacting with objects. Also, by playing games, and accepting challenges of new possibilities. A dramatic experiment showing how we see depends upon active touch was carried out at the end of the last Century by an American psychologist, G. M. Stratton, who turned his world upside down with reversing goggles. He wore these every day for several weeks. After a week or two, he found that his brain would correct for the reversing goggles, but only when he actively touched and handled objects. Unexplored objects would remain upside-down for many weeks. Then there are cases of people born blind, or becoming blind in infancy, recovering sight when adult by operations on their eyes. In some cases they can see, immediately after the operation, things they already know by touch. They remain effectively blind to untouched things for many months or even years. These they have to learn to see with great difficulty. To appreciate the importance of learning-by-doing – imagine learning to ride a bicycle which is in a glass case, and can only be controlled by push buttons! One has to fall off, to learn.

Although the EXPLORATORYseum will be the first hands-on Science centre in Britain, apart from the Science Museum’s Launch Pad gallery, many of its principles have been working for years in the late Frank Oppenheimer’s pioneering Exploratorium in San Francisco, and in several interactive Science and Technology Centres in America and Canada. There arc now about a hundred, though some have specialised activities and are not fully 'hands-on’. They are linked by the flourishing Association of Science-Technology Centers 'ASTC', which produces informative publications especially: 'Exploring Science: A Guide to Contemporary Science and Technology Museums’. (Available from ASTC, 1016 16th. Street NW, Washington DC, 20036.) This outlines the widely different aims, and gives the vltal statistics of Science Museums and 'Experience Centres' all over America. There are also affiliated institutions in other countries, among the most ambitious and successful being the Ontario Science Centre in Toronto. Here we are looking at a rapidly growing industry with a total operating budget of the ASTC members in 1977 of $94,791,000. Two years later, 1979, this became $120,051,000. The annual number of visitors for 1977 was 34,355,000 which rose, by 1979, to 37,582,000. We do not have later figures, but these could well have doubled now by 1984, for this is truly a growth industry in the States. A current estimate is 40,000,000 visitors this year.

Some of these Science Museums and Experience Centres are specialised to a region’s, or sometimes the founder's particular interest. For example, Miami’s Plant Ocean has theme areas including continental drift and 'water as a chemical’. Health, energy, and astronomy based on a planetarium and sometimes a Space Centre are favourite specialisations. Thus the Hall of Life in Denver Colorado has the slogan 'Discover health for yourself', with the aim of preventing illness by increasing knowledge and suggesting rules for healthy living. The Technological Museum in Mexico City specialises in electrical and other forma of energy. A pioneer Space Sciences museum, which also has a general hands-on science room, is the splendid Reuben H. Fleet Space Theater and Science Centre in San Diego. Most Centres cater for adults and children, and they tend to be visited by families on a day trip. Some cities have a Children’s Museum or 'Experience Center’: notably the Children’s Museum at Boston; the Capital Children's Museum in Washington, which emphasises hands-on activities, and the Children’s Museum in Indianapolis which has life-sized dinosaurs and a Victorian railway depot with a 55 ton wood-burning locomotive, with various events arranged through the year. So there is plenty of variety over there.

## Plores for Exploring

The word 'explore', from which we derive our name the EXPLORATORY, has the Latin root 'explorare' – to search out. Although 'exploratory' is not given as a noun in the O.E.D. there no reason why it should not be accepted as a noun, by analogy with familiar words derived from activities such as 'Observatory' and 'Laboratory'. Just so, 'Exploratory' is the noun of the activity of searching out or exploring. 'Exploratory' is closely related to the American 'Exploratorium' but it is simpler and it is already familiar in English, though not as a noun. The name EXPLORATORY reflects due deference to Frank Oppenheimer’s pioneering Exploratorium, while the difference guards against confusion.

'Plore' is coined because there is no existing word having the required meaning. The equivalent museum words 'Demonstration', 'Working Model', 'Artefact', or the most commonly used, 'Exhibit' (which one may note can be used as a noun or a verb) are far too passive in meaning and specifically associated with passive viewing; but we wish to include the touching, handling and generally active exploration which is the essence of the EXPLORATORY. So we call our hands-on models, experimental apparatus, puzzles and games-against-nature 'Plores' – to be explored in the Exploratory by Explorers.

Justification for our coined word 'Plore' is undoubtedly controversial, though we note with some pleasure that it is becoming generally accepted. It is derived from 'Exploratory' by extraction of the second syllable – Exploratory – with the addition of the final 'e' to make it a respectable English word. (Plore puns are a hazard. The workshop is the Plorabunda, which will become rich with the spoils of time as full many a Plore is born – surely not to blush unseen!)

## The Design of Plores – with Examples

Plores, for exploring, may be extremely simple or they may be complex examples of technology. We shall concentrate at least as a start on Plores which, though simple and generally inexpensive, are intriguing. Some produce a genuine gasp of surprise, with a dawning insight of understanding which can illuminate whole area of a person's mind. This, in turn, can induce a sense of confidence which is individually and socially rewarding. It is particularly pleasing when one sees this happening to a visitor as he or she plays (almost like a child) with a model or puzzle, perhaps of wood and string, which illustrates a novel aspect of nature or the nurture of our technology. We have seen this happening particularly with the 'Pendulum Plores'.

The Pendulum Plores stand about two feet high and have fishing-line strings supporting swinging bobs, which are small magnets. These allow the swing to be self-maintained, for any amplitude or frequency, with an unobtrusive electronic system which senses the arrival of the bob and gives it a discreet boost. The swinging pendulums make a lively sight. They attract visitors who can set the length of the string to change the frequency, and vary the mass of the bob (by putting weights in a swinging scale pan) and so discover the essential laws which led Kepler, and later Newton, to appreciate the principles by which Earth and planets move. They give a feel for effects of mass, inertia, friction (because of the need for the self-maintaining system) and they at once relate to the fascinating history and technology of clocks. Further (we believe that this is novel to the EXPLORATORY), we vary the maintaining force – essentially gravity – to translate a pendulum to the Moon or another planet,. When a strip magnet is placed under the magnetic bob it attracts the bob and the pendulum speeds up – as though it were. affected by the gravitational pull found on a massive planet. When the magnet is reversed, the frequency falls – as for a pendulum on the moon. This asymmetry between changing the mass of the bob (by adding or subtracting weights), which has no affect on the frequency, and effectively changing gravity which does affect it, may suggest all sorts of implications. Some of these may be made explicit by further Plores. Or the pendulums may stand alone. Such choices determine how the EXPLORATORY will grow, and its growth will depend on what we learn from our visitors.

The various EXPLORATORY events we have organised to date have not only provided welcome publicity for the project, but they also have a more serious purpose. The EXPLORATORY is a new idea, at least in this country, and this method of presenting science and technology to a wide public is essentially untried. These events provided an opportunity to observe people's responses and to test out new ways of presenting ideas, ways of thinking, and revealing how things work. The exhibitions, and comments of visitors to the Duckmoor Road premises, are valuable for tuning the Exploratory philosophy to people's interests and needs. So they are, in effect, a proving ground. Already we have learned a great deal about the robustness and effectiveness as the Plores (nonce of the pendulum strings got broken!), and about the fascinating and not altogether predictable ways in which people react to this new approach to finding out about the world, and something of themselves. We have a great deal more to learn, and indeed the processes of testing and modifying the Plores – and creating new plores – will continue through the entire life of the EXPLORATORY.

The Plores as so far built (which have formed three exhibitions) are an embryonic Exploratory. They start with human perception – how we see and hear and touch, and how we are sometimes deluded. This leads to the world of materials and structures: how bridges are built and support loads, sometimes failing, and how aeroplanes fly. There are elliptical billiards tables – showing how balls bounce much as mirrors reflect light. When, however, the balls graze the cushions, or they spin, this simple 'perfect' physics breaks down and we discover the complexities and in some sense imperfections of the world. This distinction between Platonic perfection and what actually happens is important for designers and engineers, and generally for applying science, or theoretical or computer models. We have brought out this essential point in several ways, including a novel game in which balls are bounced from adjustable mirrors, to hit a target. First, the mirrors are set by looking down on them, judging the angles according to Euclid; then, when the target is hit, the Explorer can look along them to compare the Euclidean geometry of light with what happens to the balls which are subject to friction and other practical imperfections which are vital to the engineer. These are games – games which children and adults can play, and clearly enjoy – but one ends winning understanding.

One cannot expect the visitors – the Explorers – to appreciate the significance of Plores without some help. Some may be self-evident, but this cannot be the rule for it is necessary to know what to do and to have some guidance of their implications. Visitors may also want to know the history, and the theoretical or practical interest of what they discover. So there must be available information, in the form of captions or by more sophisticated means such as computer displays. (The problems of presenting information are discussed, quite fully, in an appendix.) As Frank Oppenheimer learnt at the start of the San Francisco Exploratorium, it is most valuable – indeed essential – to have what he called 'Explainers' who are continually available to help, encourage, and offer advice and information. We shall do the same, as an essential feature of the EXPLORATORY, though they will be called 'Pilots' to guide our Explorers in their adventures into the wonderful world of science and technology.

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R.L.G.

# A P P E N D I X 4

## BASIC AIMS AND WORKING PHILOSOPHY OF THE EXPLORATORY

The EXPLORATORY is designed to introduce and attract children and adults to Science and Technology, with the primary aims of showing people how things around them work and helping to make the scientific way of approaching questions and problems more central in our culture. It should, thus, be a step towards melting the Snow dividing the Two Cultures: Art and Science.

The EXPLORATORY is not a museum, nor is it a school; though, like museums, it should be a valuable resource for schools. It is intended to be a try-it-yourself Science and Technology Centre where children and adults have the opportunity to discover principles of science and how things work, with 'hands-on' interactive working models, demonstrations and simple experiments. Information, advice and help will be provided by captions (written at various levels) and by specially trained explainers (called 'Pilots') who will also look after the 'Plores' and generally see that the EXPLORATORY is running properly.

As the usual museum terms, such as 'exhibit', are too passive for the EXPLORATORY interactive models and hands-on experiments, we have coined the word 'Plore': meaning a model, an experiment, or a problem of whatever to explore. So one ex<u>plore</u>s Plores. Coining some new words appropriate to the aims, should help to reinforce the differences between the Exploratory and a Science Museum.

Both, of course, have their place and there need be no competition or rivalry between them. Essentially, the Exploratory is not a custodian of historically important or valuable objects, which need protection, so we can dispense with glass cases. We are concerned with <u>principles</u> rather than with <u>things</u>. The Plores, many of which will be specially designed in-house, will be the means for conveying principles of science and how these principles are applied in technology.

The EXPLORATORY will show how familiar tools and toys of technology work. Also, how they embody principles of science and technology, which are brought to bear on solving problems by human intelligence. A conclusion is that technology is the mother as well as the daughter of invention.

Now we shall try to set out the aims and general structure of the <u>Exploratory</u> as presently conceived.

The working demonstrations and simple experiments for the 'explorer' to try out. These will start with human perception: with the Explorer-visitor finding out how the senses provide information to perceive and understand the world – and sometimes misperceive and misunderstand. There will be a wide variety of perceptual experiments on seeing, hearing, touching and the other senses: starting by looking, inwards at perceptual phenomena to suggest, by direct experience, insights into essential processes for gaining knowledge, which are still not generally considered in schools. With simple experiments, we shall show physiological and psychological principles of perception and learning; as well as sources of illusion and error. Many illusions are fascinating phenomena which are well worth considering: though they are strictly 'outside' physics they are 'inside' and essential for us. From perception and learning, we move to principles of mechanics and physics and other sciences and how they have combined to achieve the results of technology". This ranges from simple mechanisms, such as locks and keys, and kitchen scales, to computers.

By making how things work less mysterious, and making science and science's ways of thinking more generally available and more central in our culture, we hope td increase personal and national confidence and effectiveness surely leading to rich successes as opportunities are created and become visible.

Principal Exploratory Principles

1. The opportunity to try things out hands-on (rather than the push buttons and glass cases of conventional science museums) allows our visitors – the Explorers – not only to appreciate how moving models, mechanisms or whatever work, but also to discover conditions under which they do not work – and so the range of conditions in which things work or phenomena occur. For by active trying out and playing, optimal conditions can soon be discovered and tested – which is the basis of learning any skill. By optimising conditions we gain the kind of understanding which may be non-verbal but which underlies all manner of skills.

By optimising conditions for making things happen, we learn how carefully or well something needs to be done, and what can be left to inattention or chance. This is important, for saving time and effort by restricting attention to where it is most needed frees the attention, in a well learned skill, for noting (and perhaps going on to explore) alternatives – even occasionally for inventing something new or a new way of doing it.

2. Essential for the enterprise is an atmosphere of good humour and tolerance, combined with an element of challenge. Young animals and children learn by play, so it is strange that many educationalists still think of play as a trivial activity. In the Exploratory, many of the Plores should be fun, as games are fun. Many indeed can be games: games played with friends and (as science is) games played against nature. There is a place here also for some jokes; for Jokes are surprising juxtapositions that jolt the mind, perhaps into higher energy orbits with new potentials. Humour can be in the Plores themselves and in their captions; though restraint is needed, for humour can trivialise.

3. Some Plores should be surprising. These attract particular attention. And by showing up the Explorer's failure to predict correctly they at once reveal gaps in his or her understanding. For example, blowing air between the suspended balls of a Bernoulli demonstration is surprising, in the right kind of way, as most people expect the balls to separate, instead of coming together. By playing around with the air jet it is easy to discover the range and limits of the phenomena. The practical importance of this curious effect can be demonstrated in the lift of the upper surface of aircraft wings – to show that our failed predictions signal gaps of

understanding or intuition, which can make us miss highly significant facts and ideas. This practical implication may be needed for some people to justify the jolt of surprise by failed prediction. (This signal to look further and learn more is an alternative to correction by teachers which has obvious advantages; for example that surprises, but not teachers, are always available.)

There should not however be too many dramatic surprises or the EXPLORATORY will be confusing. It is reassuring to get things right – so some initial hypotheses should be confirmed!

4. There is an intention, in the long run though not in the initial phase at Temple Meads, to have a Magic Theatre for conjuring. (This will be run by Davenports, who have the world's largest collection of historical conjuring props and a major library.) This later addition seems Justified within the general philosophy, as conjuring is the extreme case of perception deviating from understanding. To bring this out effectively there is no need to explain everything. What is important is that without some scientific understanding the whole world looks like a conjuring trick. Conjuring tricks have a largely unrecognised place in the history of science. Being fooled by Conjuring is essentially failing to follow underlying mechanisms or processes which are causally necessary for what is happening: then appearance separates from understanding. At least historically, we tend to fill the gap with occult explanations of magic. A striking example is the history of the mariner's compass, which started (4th. Century B.C. in China) as magic; but it worked too well for this to remain plausible, so it became accepted in technology, even though it remained essentially mysterious – as much of science still does today!

5. Several of the Plores should be designed to reveal hidden features of the world; especially features that cannot normally be sensed. This can be done in two ways:

5.1 By making features of the world that cannot normally be sensed or perceived directly, available to the senses by often quite simple means: for example, magnetic fields made visible with iron filings; pressure-waves of sound made visible with the gas flames of a Rubin Tube. Or, more interactively, handling a spinning gyroscope wheel, which allows surprising and usually hidden forces to be experienced – literally – at first hand.

The entire point, indeed, of technologies such as Radio and Television is to make audible or visible features of the world which are normally beyond the limits of sensory experience. By starting with human perception, these technologies, and how and why they work, take on an immediately human significance.

5.2 By careful groupings of Plores, to show abstract conceptual relations. For example, models of conic sections and elliptical and parabolic billiards tables, show wonderful properties of nature which underlie the motions of planets and the optics of telescope mirrors. While each cut cone is evocative, together they allow one to appreciate significant generalisations – and at the same time, how special cases can be important. Similarly, examples of resonance show a very general principle which applies to a vast range of phenomena, and to many technologies – from clocks, through electrical phenomena and musical instruments, and the mechanisms of hearing, to the fundamental dynamics of matter as seen in chemistry.

This extension of perception by interacting and playing with forces of physics is an essential aim of the EXPLORATORY.

6. Not all Plores need to be completely understood to be successful. Some, indeed, should raise very difficult questions, to which perhaps no-one as yet has a complete answer. Setting up interesting questions may help people to enjoy living with questions. Puzzling Plores, especially Plores that please, may help to reduce the, surely, too-common fear of questions. It is an important point that Puzzling Plores may be simple and familiar. A good example is the question: Why does a book, or oneself, appear horizontally but not vertically reversed in a looking-glass? (Is the asymmetrical reversal, from the symmetrical mirror, due to optics; to a cognitive or 'mental' reversal; to something Kantianly odd about space – or what? Many philosophers and scientists get this one hopelessly wrong as we show in Appendix 5.) Another example is 'Newton's bucket': this shows, incredibly simply, the puzzling Mach's Principle, which is a basic issue for Relativity Theory. Though we may all be familiar with what happens to the curved surface of water in a spinning bucket – how many realise that it poses fundamental questions of relative or absolute motion? In both these examples it is important to make the context, and what the problem is, clear – without being intimidating. We have a lot to learn to do this well.

7. Some Plores should show how physical principles are combined in novel ways, in technology, to produce (generally though unfortunately not always) desired results. Where results are undesirable, it may turn out that the new problems can be solved by applying science with further technology. These may, indeed, be spurs to invention rather than grounds for pessimism.

8. The EXPLORATORY is primarily intended to capture people's imagination; it does not have to be anything like as thorough or complete as a School or a University. Topics and individual Plores can be chosen and designed to evoke interest and stimulate curiosity, without the necessity for a complete account. Explorers will be encouraged to fill gaps by thinking for themselves and seeking further information – which is richly available though largely untapped. Once people's interest is aroused they will surely make far better use of the available libraries, television programmes – including the Open University courses and programmes – and so justify more fully the National expenditure on these resources.

9. Although history is not the main aim of the EXPLORATORY, sequence of development. and invention are helpful for understanding – and they give a structure in human terms which is highly appealing. To get a feel for the processes of invention it is essential to have some historical sense.

We generally think of museums (which the EXPLORATORY is not) as Time Capsules, protecting precious objects of the past from damage, or up-dating, by their glass cases. In the EXPLORATORY, time-travelling can be far more rewarding than simply by looking at old things, for here we can touch and use, and play and experiment with the kinds of tools and toys that were familiar in the past. We may measure the speed of sound as Newton did by clapping his hands to the echo; measure the speed of light, and of nerve impulses, with the increasing accuracy of new techniques and instruments, as they were in turn invented. This will bring out clearly and dramatically (as the past is re-lived) the intimate relation and the mutual gains of all manner of techniques, tools, and instruments with science. For an example of hands-on 'time-machine' exploring: one can carry out Galileo's experiments with weights rolling down inclined planes, with the methods then available for observing and timing their fall, gust as it was done early in Galileo's and Bacon's Seventeenth Century. So here we may come to appreciate, by our own experiences and difficulties, what past science and technology were like – and how we have advanced and may now move further on.

There is no obvious limit to this approach from the past to the present, to anticipate and invent our future with creative intelligence guided by understanding Science and Technology.

The issues of how information should be presented are so important that they justify fuller discussion.

## PRESENTATION OF INFORMATION

The danger on the one hand is to trivialise, on the other to intimidate. This applies both to the Plores and to the Captions and other means of presenting information. To be effective, attractive and fun, Plores should so far as possible be designed to require only minimal – or even no – instructions.

### 1. The Advisers – 'Pilots'

Frank Oppenheimer soon discovered that an essential to success is to have freely available advice and help from what he called 'Explainers'. In the Exploratorium these are mainly students, wearing distinctive clothes, and they are vitally important for ensuring a warm and friendly atmosphere as well as showing people what they can do and what they can discover. They are not teachers in the usual sense; and frankly, even teachers of the best will can come between their pupils and the phenomena and wonder of the world, which we particularly wish to avoid – hence individual exploration. There should be plenty of activity going on, and also quiet places for individual thinking. Readily-found information should encourage imaginative and directed exploration; new techniques for providing information will be tried out and developed. Based on the American experience, and also from our own experience in our three exhibitions, we regard it essential to have, continuously available helpful people (who may be university students, retired teachers and academics, or people from the professions) to show people what to do and the implications of what they discover. They will be the 'Pilots' guiding our Explorers.

### 2. Information in Captions

Some of the Plores should be so simple that the Explorer can appreciate their use and aim with little or no instruction or comment. The point should, ideally, be obvious as soon as they are used; and as many will be in continuous use they will show off to people watching what they do and how to do it. But even when what to do is clear, what it means may be difficult to appreciate. But this is indeed inherent in science – as science is difficult! Much of its persisting fascination is, however, that its difficulties draw one on to deeper questions, so for anyone involved it is continuous adventure; but the 'endless question' notion is unlikely to appeal to children, or even perhaps to most adults. Our primary aim here should surely be to try to make clear, when possible rapidly and easily, something of what the experiments mean. We may then indicate that this is not the whole story, and that to go further (though perhaps later) could be interesting and worth the effort.

This point, and the consideration that there will be a very wide range of ages and educational backgrounds, suggests that there should be different kinds and levels of information-sources. These should be clearly distinguished (as for example a blast of mathematics could be a put-of) and help may be needed for appropriate selection. All this, however, can be 'tuned' by experience. The first essential is to have captions explaining as simply as possible what to do; what to note as especially interesting; minimal information for appreciating what is going on; fuller background and other information (to be selected if required); some questions raised; guidelines for seeking further information etc. outside the EXPLORATORY.

As a general point (and hare we may deviate from current museum practice) there can be a lightness of touch with humour in much of this. For example, the necessary kinds of captions may be distinguished with amusing signs (which may be little coloured models) such as:-

<u>A Hand</u> - – - Explaining what to do.
<u>An Eye</u> - – - Pointing out what to see or especially note.
<u>A Brain</u> - – - Information – for understanding.
<u>An Ear</u> - – - Questions. (The little ear model shaped like a question mark.)
<u>An Appendix</u> - – - Information for further (though not now essential) digestion.
<u>Feet</u> - – - How to seek information beyond the limits of the EXPLORATORY.

The <u>Appendix</u> and <u>Feet</u> information may be available as publications in the Science Shop. There may be specially written sheets or publications; and lists of key references, preferably available in school or county libraries. There may also be suggestions for school or home experiments. There is a case for some classically important papers to be available, as the history of science and technology is of course very important and fascinating – especially as one gets to understand the principles involved and the drama of discovery and invention.

It is important to avoid information over-kill, producing King John's reaction: 'Zounds – I am bethumped by words!' This should in part be avoided by clearly indicating kinds and levels of information that are available, so that the Explorers can select what they need, and what he may like to take up later. For selecting information, we may consider also:

Captions which are 'directional' – so that the text changed (by passive optical means) as the reader moves past, or round it. (There are snveral possible ways of doing this which we are devising.)

Standard VDU displays – which may be interactive with questions and answers. (Programs are now available for doing this.)

Interactive video disks – run with a micro computer these will be extremely powerful; though with present technology expensive in the first instance. (Thorn-EMI have offered to make one for us, free.)

The Science Shop will have a wide range of publications for sale, and also materials for home and school experiments.

Whatever the techniques of presenting information, a basic problem is the language and analogies to use for conveying novel ideas. Technical terms such as 'inertia', or certainly 'moment of inertia' will not be generally understood and they may be a put-off for many people. The same is true of mathematical symbols. Having the various types and 'levels' of explanations should help – and indeed this seems the only solution to this most difficult problem of presentation, which is perhaps less of a problem in schools because of similar ages and educational levels in each class.

It should be rewarding for a thoughtful Explorer to go through a sequence of increasing-depth descriptions and explanations. In any case it is important that different 'levels' of explanation are not all presented at once, but can be selected as required. Just how to do his remains to be worked out: new information technology techniques should be helpful here, perhaps especially computer-controlled interactive video discs.

The EXPLORATORY will become a centre for learning how to learn and how to present information and ideas. It will remain alive just so long as we go on questioning and learning how to solve these problems which are at the heart of education.

## 3. Information in Plores

Many of the Plores should be as simple and as self-evident as possible: requiring little or even no caption-giving explanation or information, at least in the first instance.

Almost all will, however, have implications – and sometimes an apparently simple and 'obvious' phenomenon can be difficult to explain in depth though; it may be highly suggestive with incomplete understanding. This is indeed the rule. It is so for most of us, for example with candle flames, soap bubbles, gyroscopes and magnets. Not all needs to be explained at once, and everything that is suggestive and intriguing inspires individual exploration – which is the point of the EXPLORATORY. The grouping of Plores can show underlying concepts. For example, by placing coloured pigments, butterfly wings or diffraction gratings, prisms or artificial rainbows together, we see Newton's general concept of white light made up of the spectral colours and how colours can be produced from white light – both in nature and in art. Although not clear from either Plore alone, together they provide a powerful and deep message which is almost impossible to convey in a book. This becomes even clearer for dynamic principles of mechanisms or processes which must be experienced as working to be appreciated.

Many of the Plores should be presented as <u>experiences</u>, such as feeling gyroscopic forces, and perceptual phenomena of seeing, hearing and touching.

Results of experiments should appear as <u>soon</u> and as <u>clearly</u> as possible. This presents very real problems as some processes simply do take considerable time. Where Explorers will return (especially school parties) we may be able to run long-term experiments, for example on genetics with flies, or growth of plants. But on the whole we should choose experiments and demonstrations which yield rapid results.

Plores should be as simple as possible – without unnecessary knobs, switches, dials etc. How things are measured should not, however, be avoided. Such constants as the velocity of light, and melting and boiling points and so on are important and have intrinsic interest. Just how they are measured should be of great interest. Physical values related to sensations have especial interest – pitches of notes should be given as the relation of our perceptions to the physical world is a primary interest though seldom presented.

Display instruments, such as oscilloscopes, are not familiar to everyone and they have to be 'read' correctly, which is not always easy. How they are set up (e.g. the time-base rate) affects their displays in complex ways. Perhaps there should be special instrument Plores, to show how they work. For if, say, an oscilloscope is not set up with an appropriate time-base rate and gain it will show nothing or nonsense. Instruments have their own fascination, and can be seen as extensions of our senses and (especially computers) of our brains. Rather than hide them away, they can be explained and used both for gaining information and for showing principles by which information is gained by organisms and by science.

Computer simulations may be useful, and indeed essential in some cases, for example for showing chemical structures. But they should not dominate, as they depart from the ideal of 'hands-on' exploration. This raises the final question: how far can 'hands-on' exploration lead to fundamental understanding? Understanding is forming conceptual models in the Mind. This process can be aided in many ways, and computer models may be most powerful. The point is that we should start with 'hands-on' interactive Plores and discover where these take us. Just as it is absurd to think of exploring as having an end, so we should not set limits now to the EXPLORATORY.

*This section starts at top of original page 60*

R.L.G. Drawings A.J.

A P P E N D I X 5

THE PLORES AT THE BRITISH ASSOCIATION
FOR THE ADVANCEMENT OF SCIENCE, SEPT. 1984

The EXPLORATORY exhibition at the Annual meeting of the BAA had the following Plores, captions (somewhat shortened here) and drawings.

A. EXPLORING OUR PERCEPTION

1. Magic Wand. (A white stick waved in front of a slide projector)
'This is a hand-waving experiment! Wave the wand in the projector's beam, and its picture appears – spread out in space by sweeping through time. This is like TV scanning, though simpler.

2. After-Images in the Eye
'Stare at the picture, then look at the blank paper. The picture appears – in reverse, like a photographic negative. Your eye (actually the retina at the back of the eye) stores the picture for a few seconds, somewhat like a fading photograph.'

3. After-Image on a Phosphor
'The paper is covered with a chemical – a phosphor – which goes on glowing after light has shone on it. (A television screen has phosphors which .are activated by the electron beams in its tube)'.

4. Wide Eyes (A pair of very wide angle telescopes, normally used for spotting intruders)
'You are seeing with extreme perspective (Plore A8). With two Wide Eyes, you can see the world in extreme 3-D over a huge range of distances – including very close when the effect is striking.

5. When is a Square not a Square? (A visual distortion illusion, in which a square on Perspex can be made to slide across radiating lines: it distorts either side of centre of the radiating lines).
'When it is distorted: – as in this visual illusion, produced by the radiating lines. Is this because they are perspective lines – normally indicating change of distance'?'

6. A Dishy Illusion (A pair of kidney dishes: one looks larger than the other, according to how they are placed).
'Are they the same size? Try moving them around. You can make the small one larger – and of course the larger one smaller. Any idea why?'

7. The Cafe Wall (A striking visual illusion, in which a chess board pattern shows marked wedge distortions which chance as alternate rows are shifted across).
'This is named from seeing these dramatic wedge distortions in the tiles of a 19th Century

cafe, at the bottom of St. Michael's Hill in Bristol. How can an essentially symmetrical pattern produce these long asymmetrical wedges? They reverse when alternate rows of squares are shifted by one square width. Try it.'

8. Perspective Shadows (Shadows from a point source light).
'What is perspective? The small source of light produces sharp shadows of anything placed between the light and the screen. The shadow, for example of your hand, will halve in size with each doubling of its distance from the light. So e.g. the wire models look distorted: the parts nearest the light looking too large. But this is exactly the 'distortion' that the images in the eyes have whenever you see objects at various distances. It is also the 'distortion' that artists use to represent distance in pictures: they draw distant objects by perspective, as smaller – just as for these shadow projections.'

9. The Skeleton Cube that shows the Bones of Perception. (A slowly rotating wire cube)
'The skeleton cube sometimes appears 'correct' – but it will spontaneously flip in depth; so that the back appears to be the front. Then ft reverses its direction of rotation, and it appears distorted. When depth-reversed its apparently further face looks too big. (This is because visual 'Size Constancy' follows apparent distance; so the reversal in depth makes the apparently far face too big, though normally it makes the front and back faces of the cube appear almost the same size.)

10. The Skeleton's Box
The rotating box will reverse in depth. Then (like Plore A9) it rotates in the wrong direction – though the skeleton (or a rod fixed to it) continues to move correctly. This is a weird effect, as two incompatible 'perceptual hypotheses' are selected ”t once when the box reverses in depth.

11. The Hollow Face (A slowly rotating thin hollow mask. It is seen as a normal face, then hollow, then normal again as it rotates).
'This face is normal – but rotates to become a hollow mould of a face. But – from a few feet away – they both appear like normal nose-sticking-out faces. This shows the power of probabilities on perception. Note, though, that when hollow it rotates backwards. (Motion parallax goes on obeying the physics of the situation; but perception has departed from the physics: for near and far are perceptually reversed. This reverses the rotation.)'

12. Eyes on Stalks (Hand held periscopes).
'Periscopes change viewpoints: in a submarine, from beneath the sea to above on the surface. Try looking through the periscopes – to make your eyes above your head, or at your knees, to look behind you.'

13. Ears on Tubes (Funnels connected by rubber tubes to the ears)

'i) Move the funnels on the ends of the tubes around – and your ears effectively move with them. You can cross them over – then someone speaking close to you from the left will around from your right.

ii) When the tube joining your ears is tapped, the sound will take different times to reach your ears, according to where it is tapped. This is experienced as a different direction of the sound. The ears can distinguish a time difference of only a few millionths of a second for detecting direction.'

14. Three kinds of 3-D Picture (Stereo pair of pictures; Lenticular screen; Hologram)

'i) Pairs of photographs, taken from slightly different positions, give 3-D depth when one of the pictures is presented to each eye. This is because our eyes normally have slightly different pictures (retinal images) as they are separated: the brain combines their two views to give stereoscopic depth perception. There are various ways of presenting stereo pairs of pictures. Pictures presented one to each eye in a stereoscope is the simplest method.'

ii) These 'lenticular' pictures do not need any special instrument. They have many vertical cylindrical lenses – so that each eye sees a different picture, printed behind them – one for each eye. (it only works from certain positions)

iii) Holograms were invented only thirty years ago, by Dennis Gabor. He invented them sixteen years before the invention of the laser – but they need laser light to be effective. Holograms are interference patterns (Plore F3) and are entirely different from ordinary photographs.'

15. 3-D Pendulum (The Pulfrich Phenomenon. This is actually a novel arrangement: the pendulum's swing is self-maintained and constrained to a straight arc, across the line of sight.)
'Look at the pendulum, with both eyes open with a dark glass over one eye. The pendulum seems to move in an elliptical path – though in fact its path is straight. This is due to the darkened eye seeing the bob slightly in the past, as in dim light the eye demands a longer 'exposure time', and so gives a delayed signal to the brain. So it is signalled as from different positions, for the two eyes – giving stereo depth.

16. 3-D Shadows (a horizontally separated pair of point sources, cross polarised to the eyes.
'This is exactly like the Perspective Shadows (Plore A8) – except that here we have two perspective shadows, one for each eye. The brain combines the slightly different viewpoints to give 3-D perception from an object, or model, which you can hold and move around. Try it!'

17. 3-D Drawing Machine (a pair of electro-luminescent image-retaining panels, on which a hand-held point source is imaged – to give 3-D drawing as the panels, in the heart of the machine, are viewed one by each eye – in a stereo optical system).
'Try drawing a knot in three dimensions. It is impossible, even for the greatest artist with pencil and paper – but you can do it with this device.'

18. Impossible Triangle (A wooden model which appears impossible from certain points of view).
'This object looks impossible, from a critical viewing position. When the two ends line up the eye – or rather the perceptual system of the brain – assumes that they lie in one plane. This false assumption generates a paradoxical perception.'

## B. REFLECTING BALLS

1. Snookered (Billiards tables with cut outs of conic sections, lined with rubber and baize).
'We have two billiards tables: one is elliptical. A ball placed at one focus should pass through the other focus, from wherever it is hit. If it doesn't, spin, or friction or some other lack of 'perfection' has deviated it from its true path. The other table has various other curves –

including the parabola found in astronomical telescope mirrors which focus the stars.

2. See at a Glance (Plane mirrors mounted vertically on heavy wooden blocks which can be moved around on a flat table. Ball bearings are directed at them, to be reflected (actually from rubber strips) to a target, or goal. What happens to the balls can be compared with optical perfection – by viewing the target as reflected from the mirrors).
'Here is a new game. The problem is to hit the target with a ball bearing – with ono. or two, or three or more mirrors in sequence. The 'perfect' law is that the angle that the ball hits the mirror (actually the rubber strip under it) equals the angle of reflection. This is strictly true for light – is this true for the steel balls? Accept the challenge of one, two, or more mirrors. Place them anywhere you like, and select the angles at which you think the ball will hit the target.
'Then give it a go. Hold a ball at the top of the chute, let it go, and see what happens. Does it hit the target?
'By looking down at the 45 degree mirror on the chute, you can see the pure perfect solution that light adopts. Does the ball behave as perfectly? Or as Milton put it; does it hit the target equally: 'With thy long levell'd rule of streaming light?'

3. Aereal Puck (An air puck that can be pushed freely on a horizontal glass table, with long magnetic cushions from which it bounces, without touching, as it has an opposing ring magnet).
'Here we reduce the annoying irrelevancies of friction – to show the perfection of Newton's Laws of Motion. Air gives virtually frictionless movements of the puck – which bounces from magnetic springs. This is about as close as one can get to the frictionless motion of the planets – which allowed Newton to describe the Universe from his first Law: A body will remain at rest, or will move at constant speed in a straight line, unless it is perturbed by external forces. Play with the airborne puck – and shake hands with Newton.'

4. Throwing Light on Light (A hidden lamp bulb seen as a real image from a large searchlight mirror).
'Some Bulbs Grow – This One Disappears!' Try unscrewing the bulb. (As it is approached, the bulb disconcertingly vanishes.)'

5. Focusing Heat (A pair of large facing parabolic mirrors with a hot filament at one focus).
'Radiant heat is just like light; except it has a lower frequency, or longer wavelength. Here, as you can feel, heat is imaged by optical mirrors.' (It is intended to show this more effectively with colour-changing liquid crystals).

## C. EVOCATIVE CURVES

1. Conic Cuts (Parking cones cut at angles to show conic sections. They can be pressed into sand).
'It is wonderful that cuts through a cone give the curves that represent the motions of the heavenly bodies. A circle is a cut at right angles to the cone's axis. Tilted a little, we have an ellipse – increasing in its eccentricity with increase of angle. This is the path of the Earth and planets. Then, with a steeper angle, we have parabolas – the path of comets that never return. Also, this is the curve of telescope mirrors, which reflect light to a focus from the stars. Then, with the steepest angle, we have the hyperbola which has a fresh set of properties.
'We may laugh at the powers of a magical pentagon: but perhaps we should pause to realise that these conic section curves are, indeed, keys to the Universe. It has not always been

obvious what is occult magic, and what is science. And as we can see in these conic sections, and in so much else, science has its own magic.'

2. Drawing Evocative Curves (Loop of string, two pins and a pencil. A wheel with a pencil on its rim).
'Ellipses can be drawn with a pencil restrained by a length of string and two pins. The cycloid is drawn with a pencil on the rim of a rolling wheel.'

3. Cycloid Races (Suitable curved tracks mounted on a (graph-paper) wall, with model cars to be released from any position along the tracks).
'On the graph-paper wall are a pair of cycloid curves, side by side. Try releasing – at the same moment – a toy car from the top of one, and from around half way down the other. They arrive at the bottom – at the same time! This is a remarkable property of a cycloid curve. Perhaps even more amazing, the cars reach the end sooner, than a competitive race down a straight track through the same fall. Try it. So, a straight line is not always the shortest distance between two points.'

D. HARMONIC MOTIONS

1. Laws of the Pendulum (Specially designed pendulums, with self-maintained swing given by self-timed magnetic pulses, and variable length and mass of the bob).
'Galileo realised that a pendulum swings for (almost) the same period with a small or a large swing. Thus he invented the pendulum clock. The mass of the bob does not matter. But as the length is increased, the period lengthens, by the square root of the length of the pendulum. These pendulums are self-maintained. You can check the laws of the pendulum for yourself by changing the length of the weight on the bob of the first, and the length of the second. (The time of each swing is recorded electronically on the counter).
(A third pendulum has a magnetic bob and a long strip magnet, which can be held under it: effectively to change gravity. Now the period changes.)'

3. The Time Machine – 'Gravity-3' – A Physics Fantasy. (An elaborate impressive looking machine having a self-maintained pendulum in a variable artificial gravity field for simulating the gravities of Moon and Jupiter compared with Earth. It has changing Earth, Moon, and Jupiter scenery, and a synchronised sound track).
'Although the mass of the bob has no effect (a pendulum with a heavy or light bob swings at the same rate) the gravitational pull under it is important. A pendulum on the Moon, or up on a mountain on the Earth, swings slower. And a pendulum on a massive planet such as Jupiter would swing faster. In this Physics Fantasy, we see a pendulum which starts on Earth and effectively travels to land on the Moon, then on Jupiter. (The 'gravitational' field is modified by magnets. This is not altogether a cheat as it does genuinely change the restoring force on the pendulum's bob, much as for a change in gravity).

E. HIDDEN FORCES

1. Magnetic Lines of Force (Iron filing, in double glass picture frames, with hand held magnets of various kinds).
'It is well known that iron filings make magnetic fields visible – Try it out.'

2. Electrostatic Force (A van de Graaf machine, with various attachments).
'Electrostatics is high voltage and very low current. This Van de Graaf machine gives thousands of volts, but almost no current, and it can keep the balls in suspension. Larger versions can split atoms.'

3. Electrical Levitation (Aluminium plates electrically supported)
'The aluminium plate is supported on magnetic fields, by induced 'eddy currents' in the aluminium'.

F. REFLECTING ON MIRRORS – WHY ARE YOU RIGHT-LEFT REVERSED, BUT NOT UPSIDE DOWN, IN AN ORDINARY MIRROR?
(This confuses almost everyone. Given, is a plane mirror which can be rotated, while remaining normal to the observer – when nothing happens. Also, a pair of right-angle mirrors, which can also be rotated – when the viewer rotates, at twice the rate, and turns upside down).

'Here are two mirrors – the first an ordinary plane mirror, the second a pair of mirrors forming a corner. Look in the plane mirror, and hold writing in front of it. Why is it left-right reversed (so that the B looks peculiar but the A does not – of the BA) though the mirror is optically symmetrical? If you rotate the mirror – nothing happens. (Actually this is very important: it is a 'control', showing that rotation of the mirror has no effect, and so is irrelevant. to the problem). But, now try same with the second mirror. Everything looks normal – as though not reflected from a mirror. Now BA looks like BA. Try rotating this mirror – and the world turns round. This is simple geometric optics.'

Why, though, does the plane mirror apparently reverse right to left but not up to down? Is this optics? Is it a perceptual phenomenon produced by the human brain?
It is none of these. If you can't think of the answer, ask a 'Pilot' – and he or she will discuss it with you.
(It was thought better not to give the answer as it is intriguing to think about: though very few people ever get the answer straight).

G. BUBBLES AND BRIDGES

1. Soap Solutions (Wire models and soap solution in a bowl).
'Films of soap adopt minimal potential energy. Wire models with bubble films show mathematical solutions which are very difficult to compute – given immediately by soap solutions! Try them.'

2. Contract Bridges (Bridges, built by Francis Evans, which collapse under certain loads)
'Why do bridges (usually) stay up? Some are in compression (arches), others in tension (suspension bridges). Both follow essentially the same curve – the catenary.

H. WAVES

1. Slinky (A coiled spring several meters long).
'Waggle the slinky spring and you will see travelling waves.'

2. Ripple Tank
The waves on the surface of the water 'interfere' producing 'beats' – due to the waves adding, ad cancelling each other periodically. This is an important principle. We can see this in the ripple tank.

3. Interference of Sound
'The two loudspeakers are driven by a sine-wave oscillator. Try moving around, in the space in front of the speakers, and you will experience loud then softer then no sound – then louder again. The variations are given by the soundwaves adding in some places and cancelling or subtracting in others. So we experience in sound what we can see in the ripple tank. (Plore H3). Combining slightly different frequencies gives corresponding 'beats' in time.'

4. Sound flames (The Rubin Tube: a long tube with small gas flames along it; a loudspeaker driven by an oscillator tuned to give standing waves in the tube, which are seen in the heights of the flames).
'The flames are higher with greater air pressure; so we see a 'standing wave', or many other phenomena of pressure changes in the air, by the heights of the flames. So we can see the physical basis of sound'.

5. Glass Fish
'These fish are largely transparent. In this 'Plore' there is a sheet of Polaroid filter at the back of the tank, allowing light to undulate in only one direction. A second Polaroid sheet is oriented at right angles – so very little light gets through. But the fish appear bright. This is because they rotate the 'angle of polarisation', actually by sugar. If this is mysterious, ask a 'Pilot' for a further explanation.'

6. Seeing Stress (With cross polarisation)
Polarisation of light (Plore H5) can be used to show stress in structures made of Perspex. The stressed regions show up as bands and patterns of coloured light which change as the local stresses change.

## I. MECHANISMS

1. Gyroscopes (Weighted bicycle wheels fitted with handles, and a freely revolving chair. This allows the hidden forces to be experienced).
i) Spin the small bicycle wheel, and pick it up by its handles. Then tilt it. You will feel the strange forces of gyroscope 'precession'. The bicycle wheel – which is a gyroscope – resists your tilting force in an odd way, as its axis tilts at right angles to what you might expect.

ii) The large and much heavier bicycle wheel allows you to make this force effective. Sit on the special chair, spin the gyroscope bicycle wheel, and tilt it. You will rotate on the chair! Just play with it and experience some fundamental forces of physics.' (Does the chair rotate because of your muscular force as you tilt the wheel, or from the energy of its spin? Check whether the wheel slows down as you make it rotate yourself on the chair. This is not as simple as it looks!)

2. Bernoulli Force
'Here are e two beach balls. Blow air between them – what happens? You might expect them to move apart. But actually they come together. This is a basis of flight. It is largely the

suction at the upper surface of wings that holds aircraft up. Actually this follows from basic physics – but it is surprising'.

J. <u>PUZZLES AND PROOFS</u>

I. <u>Proof of Pythagoras</u> (Wooden cut outs)
'We can see it is true from the wooden shapes. (Actually, this was appreciated by the Babylonians some 1500 years before Pythagoras; but he proved it, which was a great contribution of the Greeks). Here we rely on seeing that a square area is equivalent to a square number. So we see (intuitively) that the square of the hypotenuse of a right angle triangle is equal to the sum of the other two sides. But intuitions are not always reliable!'

2. <u>A Wheel that is not a Wheel</u> (Equal-diameter shapes, like 50p. coins).
'We are used to wheels running smoothly. Here are shapes which are not circular and yet they have the same diameter for any rotation. This is true of a 50p coin – which is why it works in slot machines. Try moving the Perspex sheet over them – it moves smoothly though they are not wheels.'

3. <u>Circle, Square, Triangle Puzzle</u>
'Here is a board with a <u>circular</u> hole, a <u>square</u> hole, and a <u>triangular</u> hole. Note their sizes. Ca» you think of a single rigid solid object which would pass through the circle, the square, and the triangle – such that it will, in turn, exactly fill these very different-shaped holes?

COMMENT

These are 'first level' captions, aimed at the British Association visitors: actually a great range from Nobel Prize winning physicists to (mainly selected middle class) school children. Needed, are deeper level captions and actually more difficult – presentations which do not put off (scientifically) uneducated people. We have by no means solved the problems of how this should best be done, especially as we are opposed to 'bethumping by words' with lengthy captions. Fuller accounts must be separate, and available on request. The following, is a trial example of a full discussion: reflecting on mirrors.

*This document ends on the original page 68 above the Trial Extended Essay-Caption section which has not been reproduced here.*