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LEARNING THROUGH DISCUSSION

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1 INTRODUCTION

Teachers spend a lot of their time constructing and using explanations - usually for children. In this paper we will examine the kinds of explanations groups of Primary School teachers produced when required to explain unfamiliar science to themselves. These explanations were collected as part of the work of the CHATTS (Children and Teachers Talking Science) project This two year project, part of a wider research programme on the 'Public Understanding of Science', involved a detailed study of the sense groups of people made of the science in selected popular television programmes and texts. The research team worked with small groups of Primary School teachers in structured discussions about the science behind high profile 'issues' all of which were being hotly debated in the media at the time of the research.

One essential part of all the groups' discussions was the construction and use of explanations. and this is the aspect of the project's work that will be discussed in this paper. (The appendix gives an broader overview of the project including a brief description of its main findings.) We will use the theoretical framework suggested by Ogborn (See CHATTS Working Paper 5). In this approach explanation is seen as an account ('History') of how certain real or imagined entities ('World') acted or could have acted to produce the phenomenon to be explained.

Explanation = 'History' + 'World'

Constructing explanations of scientific ideas is not a non-problematic exercise and the groups often had one of a number of different difficulties. Sometimes their problem lies in establishing what actually needs to be explained before an explanation can be proffered. Diagnosing the explanatory problem may involve characterising the phenomenon to be explained, or seeking or testing a possible 'History' or 'World'.

When either a partial or relatively full explanation is produced, its explanatory form may be either the construction of a ‘History’ from a given ‘World’, or it may require imagining a ‘World’ which then allows a possible ‘History’ to occur.

An explanation may proceed by evoking more generalised prototypes or by reference to the nature and behaviour of specific entities. A challenge through counter-example may result in the explanation changing direction or stopping.

‘Scientific explanation’ is often thought of as essentially deductive, going from general principles to specific phenomena. However, in the process of constructing an explanation, teachers sometimes worked in the opposite direction, seeking a general picture which would account for known particular phenomena. This has been called ‘abductive’ thinking. (There are arguments that it is also employed in scientific thought, but these do not concern us here.)

Other features that emerge in looking at explanations include particular difficulties that people face (especially in handling phenomena that cross different levels from the molecular to the macroscopic), the knowledge that they are able to bring to bear, and common understandings and misunderstandings.

The remainder of this paper will take a selection of examples from the data collected by the CHATTS project and show how the range of explanatory features outlined above emerge in discussions of certain scientific phenomena. From the point of view of the analysis used here, an explanation, which is a particular account of a phenomenon or an aspect of that phenomenon, is to be found in an explanatory ‘story’. These ‘stories’ - which are essentially condensed and sorted versions of the transcripts - are used in all the examples that follow. A brief account of how they were constructed from the transcripts can be found in the appendix.

2 EXPLANATORY PROBLEMS

The group may have explanatory difficulties located at one or more of three levels:

characterising the phenomenon to be explained
seeking or testing a possible 'History'
seeking or testing a possible 'World'

2.1 Explanatory problem 1: Characterising the problem to be explained

Example 1: What affects the ozone layer?

> Where does the ozone layer come into this? It's part of the atmosphere, I suppose. So you've got the same things produce heat on the earth, and the same things produce holes in the ozone layer. We know that CFCs are linked to the ozone layer, but as to these general greenhouse gases, I'm not so sure about those. CFCs are always connected with the ozone layer. We don't know whether the carbon dioxide, the nitrogen dioxide just affect the greenhouse effect or whether they affect the ozone layer as well because they were done in the programme together. What we do know is that we've got a pretty muddled picture of the planet.

Example 2: What affects the amount of carbon dioxide in the atmosphere?

> Is there anything else like trees that affect carbon dioxide? Does sunlight affect carbon dioxide? Are we saying the trees being removed could affect not just the carbon dioxide content in the atmosphere but other things? What about oxygen? Yes. The oxygen and monoxides and what have you. What about burning coal? I thought that was monoxide. In burning coal it uses up the oxygen and needs it to burn. How does the oxygen affect the amount of carbon dioxide? We breathe in the oxygen we breathe out carbon dioxide don't we. So there's that relationship. I thought there would be some sort of mixture of this oxygen with the CO2 either combining with them I don't know what the formula is...I was thinking if things breathe and use up oxygen then the level of carbon dioxide was increased. You've got gas, cars, CFCs, power stations, coal, oxygen, fossil fuels and trees

> all make a difference to carbon dioxide. What about methane, how does that react to the carbon dioxide? That I wouldn't know.

In these examples we see both groups attempting to clarify what are the phenomena to be explained. This explanatory problem is particularly prevalent in discussions of global warming where there are many entities and processes to be unravelled, particularly the difference between ozone depletion and the greenhouse effect. These examples are typical in paying much attention on what affects what, and what else might be relevant. The discussions also contain fragmentary pieces of potential explanation (for example, coal uses up oxygen) but are mainly directed to assembling a picture of what is going on, before any explaining is attempted.

2.2 Explanatory problem 2: Seeking a possible 'History'

Before a history can be constructed its components need to be established. The world it is based on needs to be laid out but not necessarily in terms of what the entities in that world are like or what they can do, but simply in terms of which ones are relevant and how they might begin to fit together to form the basis of a history.

Example 1: Which entities produce which gases?

> Aerosols making a difference to CFCs. And fridges, and fossil fuels. No they don't that's carbon dioxide. Cows, make a difference to amounts of methane. Rice, bacteria and rubbish. Is nitrogen oxide produced by cars? Carbon monoxide is. What about nitrogen oxide? That is as well. Power stations, trees, coal, North Sea Gas makes carbon dioxide. They do when they burn. Does rubbish produce carbon dioxide? If you burn it it might do. It certainly produces methane.

In the above example the explanatory problem is simply, "What would affect what in the history that I might construct?". Getting the relevant parts in place is a necessary prerequisite to accounting for events in terms of a history. In some instances the relevant events may already be taken for granted, or they may be worked out as necessary in the course of an explanation. In the above case they are quite explicitly being laid out before any explanation is attempted.

2.3 Explanatory problem 3: Seeking a possible 'World'

Example 1: How do genes fit in different shaped cells?

> All human cells aren't the same size are they? No. It depends what their job is. Cells are different shapes and sizes according to what they're doing. Therefore do genes... I mean I know this is ridiculous, but cells are different shapes and sizes according to what function they have, so would a gene adapt itself to the shape of a cell? For instance, if a gene that is round, and there are cells at the back of the eye called rods which are long, so let us say for the sake of argument that genes are round. What happens with the gene in the rod at the back of the eye? Is it still round or is it long? To fit the shape of the rod of the cell at the back of the eye? I haven't got a clue. I don't know. I thought it was something within that cell. Yes well I don't know either. I don't know whether a gene is something enclosed, an enclosed separate thing, or if it's a string of chemicals. I think of a gene as a round thing with all the bits inside, all the DNA inside, and then fit in a cell somewhere like a blob. I see the DNA as being inside a gene. Like wormy things inside which are the DNA. Well I don't know because I've got two pictures, two possibilities. There's that which I think is highly likely, and then I also visualise because I've got this notion of twist. I've got a notion of lots of strands of DNA twisted together to make this twisted structure. That isn't enclosed by anything, and therefore in the cell is a twisted thing. And that is a gene. A group of twisted things. Because that's what they were doing on there, is actually taking one of those strands like splitting it all up and taking out one. And that is called a gene. A twisted collection is called the gene. And you'd have to untwist the gene in order to get hold of one strand of DNA. And on that one strand of DNA will be all the information that you need.

The discussion from which this extract is taken had just established that genes must be the same in every cell. This leads to a new problem: given that cells are not all the same in size and shape, are genes therefore all the same or do they adapt to the cell they are in? The world of genes is imagined to try and account for the history. The role of imagination is particularly clear in this extract.

A central problem for the group, and typical of discussions about genetics in general, is that the very nature of genes, the 'World', is virtually completely unknown: "I don't know whether a gene is something enclosed, an enclosed separate thing, or if it's a string of chemicals". It does not even seem possible for the group to seek similar cases or more general prototypes. However, the discussion tries to establish the possible nature of genes at the level of the specific, whether they are containers of DNA or the sum total of twisted DNA. The group have no criteria on which to choose between the two alternatives and therefore are unable to construct a explanation for their original problem of whether genes are different shapes in different cells. The discussion stops and the account remains an explanatory problem that is not at this point resolved.

That the world of genes is virtually unknown, evidenced in the above example, also very clearly acts as a barrier for the following group in trying to put together a history of how genes affect living things. The group have to spend a long time trying to sort out the world of genes before any discussion of a possible history can ensue. It is frequently the case in discussions of genetics that only partial histories can be constructed as the groups cannot cross the initial hurdle of sorting out the world.

Example 2: What are genes?

> Wait a minute. Are the genes on the DNA? It's the other way round isn't it. No it's the DNA inside the gene. Do you get rows of genes then? I'm trying to cast my mind back many years. You get DNA which is made of those four things, as long or short as you like, and they're all strung together like a string of pearls in a different sequence, and the whole thing is the gene... is that right or not? Or you get one of those DNAs for eye colour, another one for hair colour, another one for this another one for that. They're the chromosomes aren't they. The different chromosomes are where the different characteristics are. Well what's the chromosome then? Isn't that the gene? Cell isn't too

> difficult to grapple with, that's just the whole package. The genes, the DNA, the four bases, and you've just introduced the chromosome. So your four bases make up your strands of DNA - Double helix. Is the whole lot called the gene when it's strung all together, or is it inside something else? And where does the chromosome come into it? Chromosomes are made out of genes aren't they. So where does the DNA come in? The DNA's inside the gene. The DNA's inside the gene's inside the chromosome's inside the cell. Size, is that what the difference is? I thought I understood it before. Chromosomes are made of genes. But how does that fit in with the DNA's inside the genes. Genes make the chromosomes which are inside the cell along with all the other bits and pieces. Sometimes it's the chromosome that's split up, sometimes it's the genes or the DNA that does isn't it. And sometimes it's the genes that do as well. They all change don't they. I think. All chromosomes are made up of genes, genes are made of DNA, and DNA are made of bases. So it's just a pyramid. And you get lots and lots of DNA which make up the gene and they can all change sequence can't they to make a different gene. And you get lots of different type genes to make different chromosomes. And a different sequence of bases make up different genes. They are in all the cells.

Here much of the work was devoted to sorting out parts and wholes: how the pieces of the imagined (or remembered) world fit together. Understanding the world of genetics necessitates a great deal of attention being paid to what is inside what. Towards the end, discussion turns to what genes can do. The importance of working out how the pieces of a 'World' fit together as a set of parts and wholes is often crucial and related to issues discussed in Brosnan's (1991) paper in this series.

3 MOVING TOWARDS AN EXPLANATION

When either a partial or relatively full explanation is produced, its explanatory form may be either:

the construction of a 'History' from a given 'World'

producing or imagining a 'World' which then allows a possible 'History'

We now give some examples of different ways in which a group may attempt to construct an explanation

3.1 Explanatory form 1: Constructing a 'History' from a given 'World'

Example 1: CFCs and the depletion of the ozone layer

> They help in breaking down the ozone layer. Ozone is a certain type of oxygen molecule - There might be a certain chemical reaction. The chlorine in the CFC, the chloro part, destroys, takes away, one of the ions. It affects the O3 and turns it to O2 and O2 is nowhere near as useful in filtering out ultraviolet than the O3. Because it's less dense than O3. I was thinking of my science, carbon monoxide when you inhale it, it takes the place of the oxygen in the red blood corpuscles, like a lock and key thing. And so the oxygen then can't get in. I just wondered if the CFCs had that similar effect, which in fact it does in a way, I mean it sort of breaks down the oxygen molecules. The ozone molecules have 3 atoms - It breaks, takes one away. And then it becomes oxygen. Well, it's coming back to that thing earlier where air is not moving around over the Poles. And if you get a high concentration of CFCs in that area then you get a massive destruction. The air from the Pole tends to stay put because it's dense. Sits there. And at those times and in those places, the necessary photo-chemical reactions in association with sunlight which this relies on, because sunlight is the element required to get the thing going. That happens in the permanent daylight. CFCs change to certain oxides when they get oxygen from it. I would have thought in this reaction there would be some certain elements given off. Probably chlorine, but I don't know. The planet would get hotter. More UV's going to get through and UV isn't the heating element of the sun's rays, it's the infrared that does the heating of the surface of the planet, not the UV. UV just gets there and it can cause the cancers and so on. It doesn't actually result in heating on the ground. So are we still back to the idea that CFCs are not affecting the warming effect ? I don't think they are. They're just allowing these harmful rays to come down onto the ground and give people cancer. So we've got two separate issues here, then.

In the above example there is clearly no problem of what is to be explained: the phenomenon is already established (that CFCs destroy the ozone layer) and a full and specific history accounting for this is constructed by the group. At first, a rather hesitant prototypical suggestion for the nature of the world is put forward, "there might be a certain chemical reaction", but there is sufficient knowledge available within the group to launch straight into a discussion of the specific details of how CFCs destroy ozone, where the world is known and relatively unproblematic. The plausibility of the history is reinforced by comparing it to a similar case (that of carbon monoxide), and also a more general prototype in the form of an analogy is evoked "like a lock and key thing".

The explanation of why CFCs destroy ozone at the poles proceeds in a similar way with a known world being accounted for within a history. Only when the question of what happens to CFCs themselves arises is the nature of the entities within the world less certain, "I would have thought in this reaction there would be some certain elements given off. Probably chlorine, but I don't know". One conclusion drawn from the explanation thus far and 'remembered' (albeit incorrectly) from the television programme is that "the planet would get hotter" as a consequence. This serves almost as a counter example in provoking further explanation and the final resolution that, "we've got two separate issues here".

This example is unusual in discussions of the ozone layer in that it tackles the explanation at a molecular level because sufficient knowledge is available (see section 5.4.). Compare this with other groups who are often barred from this step through lack of knowledge:

> CFCs...Is it liquid or gas?
> I also gather the ozone layer is a layer of gas isn't it? So if it's a layer of gas and there's more gases going up they combine in some way probably.

3.2 Explanatory form 2: Producing a 'World' which allows a possible 'History'

Example 1: Ozone depletion and the greenhouse effect

> Man is making an actual hole in the ozone layer and carbon dioxide is one of the gases that is doing it. Carbon dioxide makes less of the ozone layer. I suppose there must be some sort of chemical reaction. Gases eat away into the ozone layer and damage it. If they changed into something else then surely that something else would still be there it can't disappear altogether. A hole implies nothing, it can't just disappear to nothingness. I suppose it could alter into something that wouldn't have the same effect as the ozone layer. The ozone layer shields us from the sun's rays, it is replaced by the other gases which have the same effect as a greenhouse, they let the sun's rays through and the heat can't dissipate out again. It’s not actually a hole, it's a place that doesn't have the same effect on the sun's rays as the ozone. But the TV was talking about Mars and Venus and describing the gases as being thicker and thinner, does it actually get thinner then, as opposed to turning into a hole? What happens? The TV didn't say the ozone layer, it said there is a very thick layer of gases around Venus, so they let the heat in and they won't let it out again. How could that work? Like a one-way mirror! When you're talking about a one-way mirror that is something you can see through but can't see out, there is a different something on one side of that mirror - there has to be - that you can look through it but you can't look back through. It is the same thing with these gases - that from one side the sun can get through - but whatever is on the other side can't get back out again. The gas must be formed in layers or something - or is a mixture of something - and what is on the bit facing the earth doesn't let that sun go back out.

In this discussion a given history is taken up from the television programme (albeit not quite correctly in terms of the actual entities involved) and explored, “Man is making an actual hole in the ozone layer and carbon dioxide is one of the gases that is doing it”.

The process is seen firstly in the context of a very general prototype of “some sort of chemical reaction”. Whatever the gases are doing (and the analogy of eating is used) they cannot make the ozone layer disappear to nothing. This underlying principle suggests to the group a possibility for the nature of the world, that the ozone may be capable of being changed into something else, that works in a different way. In fact the conclusion is drawn that the destructive gases might replace sections of the ozone layer and act as a greenhouse rather than as a shield.

A fragment from the television programme is remembered, where the gases around Venus and Mars were described as thicker and thinner, and this becomes used as a counter example, which changes the direction of the explanation away from the ozone layer to the greenhouse effect, although the two were superimposed earlier. The group are then led to query the world that the newly remembered history is constructed out of, "So they let the heat in and they won't let it out again. How could that work?".

Here there is another fundamental paradox: something which acts differently in two directions. The problem facing the group is to know if that is even reasonable to consider. An analogy of something that works in a similar way immediately springs to mind, providing an example which establishes the possibility that the effect can exist, "like a one-way mirror!". This analogue is then explored to establish the kind of world on which it may need to be based, and then the world of the gases is arrived at by working in an abductive direction from the same phenomena. The basis of the similarity between the phenomena and the analogy is not even considered in the explicit explanation of the way in which the world must be which follows, "It is the same thing with these gases...The gas must be formed in layers or something - or is a mixture of something - and what is on the bit facing the earth doesn't let that sun go back out".

Other groups had the same problem, arising in the same way from basic presuppositions about the general way things must work:

> Because these make a hole in the ozone layer, so the sun's rays get through, but they can't get out again, so they warm up the earth. You're letting more sunlight through but these gases are preventing the sunlight, heat from escaping. Normally the ozone layer in its healthy state would be letting the sunlight in and out in proportions that are useful to living things, but we're destroying it, and letting more in than

out. The equilibrium has changed. How it's doing it I don't know. Maybe its something to do with these gases that are stopping it getting out...But they're still letting it go one way. That's what I don't understand. How it can go one way but not the other?

3.3 Explanatory form 3: Simultaneously producing a 'World' and a 'History'

In constructing explanations groups very often have to explore both the 'History' and the 'World' simultaneously. Neither can be taken as given and features of both have to be explored and related to each other in an attempt to make sense of the phenomenon. The following example is both interesting from this point of view and contains several other features of explanation.

Example 1: The balance of oxygen and carbon dioxide

Sarah:

We breathe in air and breathe out the same carbon dioxide We could live without carbon dioxide. We couldn't live without oxygen. No more of the gases are made we just breathe out the bits we breathed in. We use one bit, trees use the other, there isn't more or less it's just different bits of the world use different bits of it. In breathing surely we don't make carbon dioxide. Your body doesn't manufacture it. Are trees the same?

In a boxful of air the tree takes the carbon dioxide and I take the oxygen. ... Where does the air come from to replace it? I'm not convinced by this any more.

Geraldine:

A balance of both oxygen and carbon dioxide is needed for trees. Carbon dioxide and oxygen are still needed even if you only use one of the gases. They are sort of producing it, trees will emit oxygen. There is less oxygen because we are cutting down trees. If there is no less oxygen it is just that by cutting down trees they are not using it and not giving out the oxygen then where is it, the oxygen? Does it make it or is it just a part of nature that trees need carbon dioxide and then emits the oxygen. I don't think it's just that trees take the carbon dioxide and exhale the oxygen. You taken oxygen and given back carbon dioxide I take carbon dioxide and give back oxygen so we need each other to live. It's a cycle. We are sharing. There is more than enough for both of us in the box and we just keep going around.

The phenomena to be explained in the above example stem from the television programme and are clearly expressed in an uncontroversial history established early in the session, namely that, “Trees reverse the process they absorb the carbon dioxide. If we didn't cut down the trees they would take in the carbon dioxide and give out the oxygen”.

This seemingly unproblematic and ‘taken for granted’ history hides a great deal of complexity that only emerges later on in the session when the group attempts to explain the statement ‘trees make more oxygen’. The way in which things must work at first seems clear to Sarah. She assumes that trees and people need different gases, and so she constructs a history which shows how this can happen, “We use one bit, trees use the other, there isn't more or less it's just different bits of the world use different bits of it”. This relies on a world in which the different gases exist independently and are not converted one into another.

But at the same time an alternative history is being put forward by Geraldine, “Carbon dioxide and oxygen are still needed even if you only use one of the gases”.

In the face of this alternative, Sarah is lead to query the nature of the world that must underlie her history, “In breathing surely we don't make carbon dioxide. Your body doesn't manufacture it. Are trees the same?”.

This leads to the nub of the problem to be explained. The group does not know whether carbon dioxide and oxygen can actually be made or not, a point raised by two other individuals in the discussion, again querying the nature of the world in which the history had at first seemed straightforward:

Can you actually create oxygen?
Is it definite we don't make carbon dioxide?

In fact Geraldine starts to come around to Sarah’s perspective of a cycle of gases that simply keeps going around, in which carbon dioxide and oxygen are seen as two separate gases that exist independently of each other, with no notion that they might be might be derived or assembled from each other.

The difference of opinion is not in fact resolved, as the group can find no answers to these questions. But by this time Sarah is no longer convinced by her own history. She embarks on a ‘thought experiment’ in imagining a given boxful of air, with trees and people using the carbon dioxide and oxygen. “Where does the air come from to replace it? I'm not convinced by this any more.” This thought experiment acts as a counter example which serves to shake her confidence in the history she had taken to be unproblematic initially, and she is no longer sure of the nature of the world. The explanation ends at this point as there is insufficient knowledge available to the group for them to take it further.

Although the question of the balance of gases arises in virtually all of the discussions on global warming, this example is unusual in probing the precise mechanism by which the amounts of oxygen and carbon dioxide in the atmosphere vary, although other groups also see the gases as existing in fixed amounts that are either locked into plants or released.

4 FURTHER EXAMPLES OF EXPLAINING

Although we have isolated two main types of explanatory form, there are many cases where the accounts given by the participants do not fit neatly into one category or the other. The explanation may fluctuate between the two forms, or explanatory problems may arise which throw doubt on the explanation being proffered.

4.1. Knowing part of a ‘History’, but not knowing the ‘World’

Example 1: What are CFCs and what do they do?

> I'm a sceptic but if we are to believe what a large proportion of the scientific community is saying then those affect the ozone layer. The baddy as far as the ozone layer is concerned are the CFCs. But I don't know what they are, I've never seen one and I wouldn't recognise one if it ran across the floor. But that's what they tell me. By destroying. But how it got there. Why it punctures a hole in this layer I don't know. I think I've got a similar picture, that's what's filtered through to

> me. This gas which is emitted from aerosols would somehow ascend to the outer atmosphere whatever it is called, the stratosphere? And in some mysterious way thins this envelope of ozone whatever that may be. But what happens to the CFCs in the process I haven't a clue. I would guess that they change because most things do change. Do you think they are sort of diluted by a healthy dollop of ozone? I could be convinced by that too, yes. Your analogy of burning up holes in the ozone layer, I can picture that. That's the first impression I've got. If I'm asked to think about it, deeply, and bring some reason into it then perhaps the ozone is diluted by CFCs and vice versa and somehow get mixed up. Is ozone a gas though? I don't know. And we must get more excited that this hole is appearing over the Antarctic more than over the Arctic, or vice versa I'm not quite sure. It's this picture isn't it of the hole in the ozone layer and more sunlight it gets kind of brighter and brighter and brighter. You put more suntan lotion on down at the Antarctic, but why it should be at the Antarctic why it should be over there I don't know. Then in some way it closes up again, it gets smaller, then I stopped worrying. And will it if we all stop using the aerosol sprays. And is that the only source of CFCs, aerosols? No. It's the fridges as well. Nappies, its the bleach that goes into nappies and toilet paper. That's why we should buy unbleached stuff. You get CFCs from there.

In this rather typical account the group rehearse the account of the phenomena, taken from the television, but do so in such a way as to make problematic how such things could arise. There is much analogical thinking, looking for the right kind of prototypical process (burning holes or diluting), but directed to exposing difficulties rather than resolving them. It is not even clear what kind of cause of change to consider: whether changes to CFCs are natural or are caused. Thus the thinking is directed to exposing difficulties about what general sort of explanation to look for, that is to say, what kind of world to imagine.

The next example is similar: in putting together pieces of a history, fundamental questions and doubts about the very nature of the underlying entities, which might normally be taken for granted, emerge:

Example 2: How do CFCs destroy ozone?

> The pressure makes the CFCs into a gas, and they are coolants in fridges but not in aerosols, so are CFCs natural or man-made? Are they a mixture of various components? Do they feed on the ozone (a gas), do they multiply or just take a long time to disappear like nuclear waste? Do gases need something to live on, or isn't it that they can exist in their own right without anything else?

4.2 Making up a 'History'

In the next example new possible histories are suggested, to account for, and perhaps resolve, puzzling aspects of the phenomena:

Example 1: Why are holes in the ozone layer over the poles?

> And in some parts of the world there's a hole. Is that just because they can see it better? Or is it the wind? Or is it real. I have visions of these winds blowing these CFCs around to the north pole. Could it be to do with the poles being magnetic? Isn't it more to do with population. No there would be more where the populated areas are. There's more industry in the North than in the South. It would seem an obvious question that there should be more holes in the denser populated areas. But there don't seem to be. So there must be some reason why the CFCs are going round to all these holes. Is it to do with the way the earth spins? Because it's cold? Attaching ozone to itself. A sort of molecule joining together in a clump. That's how I see it. ....We're clear about the hole caused by the CFCs and what causes them. But how it does it we have no idea.

Here some basic ideas about the nature of a world make aspects of a given history problematic, so new or additional histories are constructed. The starting point is that if CFCs are matter, then they can only act where they are, not at a distance. This makes it a problem that they are produced mainly in the northern hemisphere and yet produce a hole at the Antarctic. Wind, the rotation of the Earth and the coldness of the Antarctic are tried out as possible additional parts of the history. A different group had much the same problem and much the same solution:

Example 2: Why are holes in the ozone layer over the poles?

> But it is in specific places as well isn't it? It's either the Arctic or the Antarctic. So why is it there and nowhere else. And how does it get there from everywhere. Is it attracted by the magnetism or something. Or the cold. It's obviously something to do either with the magnets of the concentration of the cold if there are now holes at the North pole too.

4.3 What is the nature of the 'World'?

In the following examples, the problem is reversed. The difficulties concern the nature of the entities involved (the 'World') and because this is unclear, there is a problem of arriving at any reasonable account of what they do (the 'History').

Example 1: What are genes? What is DNA like?

> I've seen a jar like they showed with strands of DNA, I mean they're surely not that big are they? Where do they come from? How do you separate DNA from a gene, what does a gene look like? I don't know. I don't know what DNA looks like, I don't know how you separate DNA from a gene, I don't know how you arrive at isolating a gene. It's very complex, and I don't know how many molecules there are of these things, how they're stacked together if they are stacked together. I know they're twisted. The strands of things that are connected together. Like you have models of them, and they were twisting things with the molecules there and strands between them. How are they stuck together? But I just know from the structure and A level that they're joined together, but like you I don't know how. They talk about using enzymes to cut DNA. Because they're attracted somehow aren't they? So there must be protein or something joining these things together. Breaks it up. like a knife surely, and if you need an enzyme it means that it is living matter that you are dealing with, and therefore you need an enzyme to cut them. But I don't understand any of it. Why are they visible hanging in a jar? What are they? I expected them to be much finer than that. And they seemed to be massively big. Surely they're not that big?

Example 2: How are DNA and genes arranged in cells?

> The information comes from their various combinations. But what they look like what shape they are, whether they're round or long or what they are I don't know. You believe they're long because you've seen the structures a collection of molecules which are formed in a particular way. But the DNA could be twisted up in a ball, or in a loop. But even if it was stretched it out you'd still have the strands. But I don't know what it looks like in the cell. Is it stretched out in the cell like a long sausage. They move though don't they? Or is it wrapped up. I don't know. What is a gene. I don't know what it looks like, whether it's round with all the DNA wrapped round it. Within the cell or on the outside. Haven't got a clue. I had a vision of twists of DNA in cells that's all.

The television programme had shown a jar containing what was said to be DNA. The jar appeared to be full of white fibres. The groups spend a lot of time and effort attempting to resolve at what level to think about DNA, about what it is and about what can be done to it and how. They have to imagine the relationships as entities of DNA and genes, and what kind of process it could be to cut a gene out of DNA. Given that DNA can be cut, how could this be so? Working in an abductive direction, ideas about how DNA must be joined are arrived at, and notions of what could break such a join are tried out.

The second example shows another clear case of an attempt at abductive reasoning: imagining the nature of things to that which is known to happen makes sense. However, the world of genes is so alien that the group are not able to reason or draw upon existing knowledge to arrive at any firm resolution. A particular problem throughout these examples is the relation between the macroscopic and molecular levels (see 5.4. below).

5 OTHER FEATURES OF EXPLANATION

As indicated in the introduction there are a number of features that are of interest in looking at explanation in addition to explanatory problems and explanatory form. Explanations may proceed or indeed stop as a result of reasoning employing one or more of the following:

prototypes
counter-examples
abduction
macroscopic and microscopic levels

We shall now discuss a number of explanatory stories, showing how these and other component features of explanation may be present and work together.

5.1 Prototypes

Example 1: Looking for a prototypical 'History' for layers of gases

> All the harmful gases mix together to make blanket, band of gases, attach themselves to different molecules to make a dense band, collect together. Maybe they are light and float to the top or maybe they are heavy and stick around the earth, but because they are more or less the same weight they stay together. Do they sit as a band or just form a part of the atmosphere?
> If it is a diffusion of gases rather than a layer it is harder to see how it works.

The problem for this group is to imagine how gases emitted at various places on the surface of the Earth come to form a layer in the atmosphere. A prototype of 'sticking together' is tried out as a way of accounting for the formation of a band of gases. But this is doubted, perhaps because gases are not thought of as cohesive. Then a diffusion prototype is considered, and an unease about how gases just mixed in the atmosphere could function as a layer emerges.

Another example concerns what prototypical history to consider for whether CFCs naturally increase or decrease in amount:

Example 2: What happens to the CFCs?

> Do CFCs accumulate gradually increasing in effect, or keep going for a long time and tail off?

Pragmatic logic suggests choosing the latter, but without any certainty:

> CFCs must eventually be destroyed otherwise why ban them? Half lives, slowly break down and eventually cease to be active?

Another prototype history is suggested by another group for a similar problem with other histories:

Example 3: What keeps gases trapped in the atmosphere?

> Why doesn't it just fly off into the atmosphere, just out into space, or is it caught there, by gravity?

5.2 Counter examples

Facts or explanations can be tested by seeking counter examples, or counter-phenomena. In the example below, a teacher questions the statement that a warmer atmosphere would increase drought near the equator:

Example 1: What climatic changes would result from global warming?

> These climate bands are going to have their positions changed....I'll tell you what makes me wonder. Warm air can hold more moisture than cold air, okay. Now, that's why you get thunder storms and things around the equator and what have you. So, you'd think that there would be more rain - but it doesn't work - it isn't working straightforwardly as that. There are other factors.

A similar case has already been mentioned: why the ozone hole is not near where the CFCs come from:

Example 2: Why are holes in the ozone layer at the poles?

> Isn't it more to do with population. No there would be more where the populated areas are. There's more industry in the North than in the South. It would seem an obvious question that there should be more holes in the denser populated areas. But there don't seem to be.

The two counter examples below were produced in connection with DNA transfer. The counter examples question whether it can be assumed that it will always work either in a natural or an artificial context:

Example 3: Can genes be passed on between species?

> You get some genes from the mum and some from the dad, or one plant and its other plant in the same species. It's got to be in the same species. It doesn't have to be within the same species though, occasionally. But you get infertile young don't you. I'm thinking of horses and mules... they can breed across species, but they're usually infertile. For example asses and mules. And mules can't go on to reproduce more mules.

Example 4: Why aren't genes rejected in genetic engineering?

> But somebody else's characteristics are stuck in there, so why does it accept it? Why don't they just reject things like sort of like human tissue rejects. It doesn't say why it becomes part of it. Do you have plant antibodies and stuff like that? Are there such things that will reject foreign matter. When you, what's it called, when you graft. It wasn't mentioned at all, everything was accepted.

For most of the groups, counter examples most frequently served to bring the discussion to a halt by shedding doubt on the explanation being generated. Counter examples can also cause an explanation to take a different tack:

> [Micro-organisms] grow on food breaking down the food substance to provide nutrition for themselves. Produce decaying. That's what moulds do. You've got harmful micro-organisms, but there are also beneficial ones. Think of the micro-organisms inside us. Digestion and such like. We'd be in a bad way without them. In some cases they are a part of the food. You couldn't have yoghurt if you didn't have the bacteria. Yoghurt is the breakdown of the milk.

In the above example the discussion turns from micro-organisms as necessarily a bad thing to be irradiated to their beneficial effects.

5.3 Abduction

The groups of teachers quite commonly worked in an abductive direction going from the specific to seek more general principles that would account for the phenomenon.

Example 1: Are genes the same in all cells in an organism?

> In a living cell. The same within one thing. I think they've got to be the same. You're saying that all the information for every being is in one cell. The blueprint for every living being is in one cell, because otherwise you couldn't grow new plants from bits of plants. You can take a tip of a leaf off one in gardening and grow a new plant by sticking it in. You can't do it with a human can you. No. You can nevertheless examine I do believe one cell, which is what they do in forensic science. I'm not exactly sure about that but I think you're right, I think that can only be, otherwise you've got to take cells from all over the body. That's sensible. They can identify taking a hair, in forensic science in police work they can identify a person from a few scraps of that cells of that person, and what's this genetic fingerprinting where they can identify people from body fluids and cells that they find at crimes. Which would indicate that every cell has the same information in it, otherwise you couldn't do that could you. No just seems remarkable that a cell contains full details for one human being. And it has to because in reproduction there's only one cell that gets through. It's got to have all the information so all the cells have got to have all that information.

The above example starts with a counter example, questioning the generalisation from genetic manipulation in plants to animals. But mostly the group are concerned with arguing for a fundamental point about the nature of the world, namely that every cell has all the DNA information in it, starting from known phenomena, namely the propagation of plants and forensic practice. The argument is in the abductive direction: to the unknown nature of DNA and cells on the grounds that such a nature would make sense of known phenomena. This example of abduction is particularly characteristic of the reasoning employed in genetics where general principles were largely unknown.

5.4 Macroscopic and microscopic levels

Notably in discussions of genetics, but also elsewhere, there were problems in relating explanations at different levels. The microscopic world has its own nature and behaviours, which do not relate in obvious ways to the corresponding behaviour at the macroscopic level. How do genes make blue eyes? How does a build up of carbon dioxide affect the world's climate? How does a dose of radiation keep a chicken fresh?

Example 1: Can you see things at a chemical level?

> You can see the chemicals [ATCG]. Wouldn't we? Would you? It depends if you're talking about separately or a bottle. They had a bottle of them on telly didn't they. So of course you can see them. I wouldn't have thought you could see those. I can't point to a bit and say that's that. But poison and toxin, what's that, if they're not [chemicals]? You can see a bottle of bleach. On a chemical, on a molecular level you can't see it I know what I'm looking at if I'm looking at a bottle of bleach, but I don't know what I'm looking at with those.

The first two examples illustrate clearly the relationship between thinking about levels and relative size. With cells and DNA there are multiple levels to be sorted out, each with its explanation located at a level lower down:

Example 2: Can you see genes and DNA?

> Well they're like a double helix, that's what they're like isn't it? Microscopic obviously. Can we ever see these things? You can see the structure of it. You can see meiosis and mitosis taking place under a microscope. Yes I know you can but that's not the DNA level is it, that's at the gene level, which is far bigger again right down here. I imagine DNA's like a cell but tiny, something closed, enclosed. No stringy. Stringy at the end. Use a string of onions. I'm sure I've seen pictures of DNA though. It's literally a spiral isn't it. Like pasta. Is it

strings of those, or are they sort of compacted together or something? I don't know what genes look like.

When explanation stretches across too many levels, it may become impossible:

Example 3: How do genes make characteristics?

How do genes make characteristics? Well is there some part of...is it in...no it can't be in the brain...co-ordinating. I find the gap too large between DNA and eye colour. It's too big.

Example 4: How do gamma rays stop potatoes sprouting?

So gamma rays stop potatoes from growing, so it has changed something inside the potato in order to do that. Or suspended it. I was wondering whether the gamma rays are doing something to the potato to keep it in its dormant state. Yes, I'm not sure what stage it has been left in, if something inside is completely different.

As indicated earlier one of the groups' major problems, exemplified in the extracts given above, was in relating changes in individual parts to changes in the whole.

5.5 KNOWLEDGE AVAILABLE

The content and extent of explanations is largely determined by the knowledge available to the group. A lack of precise scientific knowledge can act as a prompt to explore possible explanations:

Example 1: What makes things decay?

What causes the object to decay? Is it actually inherent in the object, or is it the bacteria that are acting on it? And if the bacteria is what cause it and they're not an inherent part of the object then [gamma rays] are not changing the object they are changing the peripheral...the bacteria. I understood that was what decay was, not the original object otherwise sterilization wouldn't function.

The initial uncertainty about how things decay prompts in this group an exploration of ideas which is partially resolved by the use of a counter example to support the stance taken.

In similar examples where explanations are being generated from uncertainty, a resolution may not be reached if there is insufficient knowledge to choose between more than one competing possible histories.

Example 2: How does carbon dioxide keep the heat in?

> Just think of it as another layer sitting round the earth. What do you use to trap heat? You just get a rise in temperature. But how?
>
> Claire:
>
> I would say again it is a chemical reaction, some part of the atmosphere is using heat for a chemical reaction, or consuming heat would trap it. As you raise the temperature the gas becomes more active. So you get more reactions and quicker. I was just trying to work out whether the chemical reactions cause the heat energy to be used or stored.
>
> It's not storing heat up in the atmosphere, it's keeping us hotter down here. But how? How does it prevent the heat getting out?
>
> Richard/Margaret:
>
> It's to do with long wave and short wave rays. I think as the sun's rays hit the glass they're short waves and normally they would be reflected back out again but when they are changed they become long wave and they're trapped within so it results in a rise in temperature. It must be while they are travelling through they change wavelength because if you've got this idea of a layer the only difference between those from the outside and the inside is what it reacts with in the middle.
>
> Kathy:
>
> I'm really very muddled about all this, I think there's a difference between the way the sun's rays heat up the earth and the way the earth gives off heat, and it's the way the earth gives off heat that's being prevented but the rays can still come through. But can't get back out. I don't see why it needs to change as it comes in, the heat isn't taken out by the rays of the sun is it? It would come out in a different way.

In the above example each explanation plausibly accounts for the phenomena and the group has no means by which to judge the correctness or otherwise of the alternative explanations. In other cases a lack of knowledge may stop the explanatory account:

Example 3: What do gamma rays do to DNA?

> Gamma rays stop the bacteria and the insects as well. And the potatoes, stops decay. And it stops the vitamins. It has an effect on proteins but we don't know what. The effect is problematic because they go on. Is DNA a protein? Yes, what does the gamma rays stop the DNA from doing?

Generating explanations in the discussions is frequently centred around common difficulties such as:

> How do CFCs destroy the ozone layer?
> What does keep the heat in?
> How do gamma rays stop food going bad?
> How do genes code for characteristics?

Perfectly valid explanations (albeit scientifically incorrect) may also be based on misconceptions or built around areas of special difficulty:

Example 4: Are genes made of DNA or is DNA made of genes?

> Are the genes on the DNA? It's the other way round isn't it? No it's the DNA inside the gene. The DNA's inside the gene [which is] inside the chromosome [which is] inside the cell. Size, is that what the difference is? Chromosomes are made of genes. But how does that fit in with the DNA's inside the genes? All chromosomes are made up of genes, genes are made up of DNA and DNA are made up of bases. So it is just a pyramid.

As this example illustrates, a very common problem in discussing genetics is how to think of genes and DNA. Are they separate entities, or is one made of the other, and if so which is made of which?

A very common misconception in many explanations about the greenhouse effect is to assume that it is the same rays trying to get out that come in:

Example 5: Why can’t the heat get back out of the greenhouse?

Why does it let the heat in and won’t let it out?

Taking this misconception as a starting point leads to generating very involved and complex explanations:

Example 6: How does the sun get in?

How does the sunlight get in through this blanket in the first place? If this blanket is so thick that it won’t let the heat out, how is the heat getting in there? We’re producing the heat aren’t we? When we burn things. Maybe it is to do with the coal in the air. Where the atmosphere is thinnest, then presumably the sun can get through, but it can’t get back out gain. So it is coming in through the ozone layer. And then it must be spreading out and it is not getting out. I don’t know. Anything that we do we produce heat, don’t we? So we are getting it coming in, but more is wanting to come out. If we keep pushing out all these gases, then this blanket will get thicker and thicker, eventually no sunlight will be able to get through to us. There's going to be heat without light.

Example 7: How do the gases keep the heat in?

They let the heat in and they won't let it out again. How could that work? Like a one-way mirror! When you're talking about a one-way mirror that is something you can see through but can't see out, there is a different something on one side of that mirror - there has to be - that you can look through it but you can't look back through. It is the same thing with these gases - that from one side the sun can get through - but whatever is on the other side can't get back out again. The gas must be formed in layers or something - or is a mixture of something - and what is on the bit facing the earth doesn't let that sun go back out.

As we have seen, it is not always possible for the groups to resolve the correctness or otherwise of their explanations. Misconceptions are not then a barrier to the construction or discussion of explanations. This should act as a reminder that explanations are acts of **imagination**, which are not necessarily altered by explication. 'Correct' explanations are not inherent in phenomena but are the result imagining a certain kind of world where the entities are peculiar enough to obey scientific laws.

6 SUMMARY

- The groups were actively involved in generating explanations in attempting to make sense of aspects of science through discussion.
- Constructing explanations involved characterising the phenomenon to be explained and generating a 'History' and a 'World'.
- Groups may have had problems knowing what it is that is to be explained, or what 'History' or 'World' they needed to consider in their explanation.
- Explanations may have involved producing a 'History' in a given 'World' or imagining a 'World' which allowed a possible 'History'.
- Most often, the 'World' and the 'History' were evolved simultaneously.
- Generating explanations was more often problematic than straightforward. A great deal of the group discussions centred around generating and developing, rather than presenting, explanations.
- A particular problem for groups was that they did not have sufficient knowledge of the scientific 'World' in order to arrive at a plausible 'History'.
- The groups often sought prototypes that could be used to help explain general features of specific phenomena.
- Counter examples were sometimes evoked either shedding doubt upon, or changing the course of, a discussion.
- It was quite common for the groups to move in an abductive direction from specific cases to more general principles to account for the phenomenon.
- The groups had difficulties in relating changes at a microscopic level to macroscopic features.
- The knowledge available to the group determined to a large extent the content and extent of an explanation. Lack of knowledge either generated or retarded explanations.

- Groups often did not have the means to choose between competing explanations. Explanations were quite frequently built up around common misconceptions which were not always resolved by the end of the sessions.

APPENDIX
1 AN OVERVIEW OF THE CHATTS PROJECT

The CHATTS (Children and Teachers Talking Science) project lasted for two years and was part of a wider research programme on the 'Public Understanding of Science'. It involved a detailed study of the sense groups of people made of the science in selected popular television programmes and texts. The research team worked with small groups of Primary School teachers in structured discussions about the science behind three high profile 'issues' all of which were being hotly debated in the media at the time of the research:

Unlike much other recent research into Primary School teachers' understanding of science, CHATTS was not concerned with snapshot responses to situations or questionnaires indicating what teachers do, or more commonly, do not know. CHATTS was interested in the *process* by which teachers can *come to make sense of science* under favourable conditions. The public in general receives much scientific understanding from the media: issues we hear about in the news and read about in the papers. Such science is of interest and concern to us. CHATTS therefore elected to focus on current science issues with a high media profile as a starting point for investigating how people come to make sense of, and use, the information presented in constructing their own understandings.

WHAT DID WE DO?

In total, 69 discussion sessions were run involving over 175 practising and student teachers. Each group talked about one of three areas.

- **global warming** - the greenhouse effect and the ozone layer
- **food safety** - particularly food irradiation as a new technology
- **genetic engineering** - manipulating our inherited characteristics

The participants were volunteers from schools in London and the Home Counties, and from initial and in-service training courses at The Institute of Education.

Teachers watched excerpts from BBC TV Science output, for which:

• the topic related to the Primary curriculum

• the issue involved was of public interest and concern

• the scientific content was substantial, requiring some effort to understand

• other supporting materials were available.

Each group containedabout four teachers and met twice with a group leader (one of the project team), for about one and a half hours each time. The first discussion had three activities:

• sorting of cards showing scientific terms

• building up and discussing ideas about causes and effects

• summarising ideas expressed so far.

Reading material for the second session was provided. At the second session, groups:

• discussed a magazine article on the same topic using a DARTS type activity

• constructed a chart showing how their ideas fitted together

• discussed children's ideas about the topic and how to respond to them.

These activites were designed to provide a focus and structure for discussion, not to be completed in a mechanical manner. The card sorting familiarised the teachers with the entities discussed in the T.V. programme; the 'cause effect' and DARTS activities gave the opportunity to examine individual apsects of the science in some detail; and the construction of the chart and 'summarising ideas' activities the chance to put the pieces back together again.

The role of the researcher running the session was as facilitator not as director. We did not try and influence what people said, as from a research point of view it would be counter-productive and also the teachers would not have gained from it. As the research was trying to elicit teachers' understandings we did not give answers as we went through the sessions, but we provided a pack of additional material to take away and answer outstanding questions at the end of the session.

The idea then behind the sessions was to give teachers the freedom to discuss the science at their own level, selecting their own problems, while at the same time providing a firm structure and appropriate prompts to keep the discussion flowing.

Using the activities for INSET

The activites described above have formed the basis of an discussion based INSET pack in primary science - The 'CHATTS Pack', In addition to the materials required to rne the activities the pack contains guidance (including a video) to help the INSET providers (including school science co-ordinators) run their sessions more effectively.

WHAT CAN WE SAY?

The most important result of the project required no detailed analysis but is evidenced by the fact that we have over 2000 pages of discussions about science to analyse. It is simply that:

- **Primary school teachers can and do make sense of science through discussion.**

This is in direct contrast to the received wisdom. It has been a feature of other Public Understanding of Science research projects, particularly those concerned with controversial issues, that they have found it difficult to get people talking about the *science* underlying the issue. They have found that people are happy to discuss for example moral, political or economic aspects of the issue, but not the underlying science. We believe that this difference is a function of the nature of the tasks used to prompt discussion. In the CHATTS discussions the tasks were such that the science was seen to be of central relevance, it was therefore without exception, the central topic of discussion. Where moral or ethical considerations were introduced this was done in the context of talking about the science.

The next three points concern the consequences of this talk on the teachers own understanding and metaconceptual awareness:

• **The teachers can gain confidence and understanding by discussing science seen on TV and in print.**

Given well structured discussion activities, primary teachers can and do engage in a serious attempt to think through the science for themselves. This works because their own ideas and ways of thinking were valued and used. By revisiting aspects of the science from a variety of perspectives the teachers gained confidence in their own ability to make sense of ideas which at first they may have felt they did not understand at all.

I'm not very clear about this. While you were sitting talking there, I was saying to myself "I don't believe that". I understand that the ozone layer was filtering the sunlight but then these other gases are disturbing the climate because of the greenhouse effect. I think it's probably quite right, there is a difference between the ozone layer and the greenhouse gases.

All the members of the group participated in the discussions, working together, to talk about the science for a total of three hours. Although references were made to everyday and ethical issues, these most often illustrated or lent weight to scientific points and rarely distracted the teachers from the task in hand.

The teachers were actively involved in generating explanations, both for themselves and for others, in attempting to make sense of the science in the discussions. They became aware that through this group process they were individually learning more about the science which was of both personal and professional benefit.

Then that's lovely because our children would identify with that as well.

• **The teachers can clarify what is not yet understood, providing a path to further understanding**

An important aspect of confidence is clarifying what is not yet understood, which provides a path to further understanding. The discussions are not a panacea for all the problems of primary science, but the teachers appreciate the significance of the science they have discussed and are often clearer about what else it is they need to know. They can then be more selective and more receptive to subsequent inf□rmation.

And it makes you more interested to go now and check on all these things and find out a bit more about it yourself.

The discussions may leave some questions unanswered, but the nature of the questions have changed to become much more specific and pertinent to their personal needs.

It would seem an obvious question that there should be more holes in the denser populated areas. But there don't seem to be. So there must be some reason why the CFCs are going round to all these holes. Is it to do with the way the earth spins? Because it's cold?

- **The teachers know they know more science**

What amazes me is how much we do know and I don't think any of us actually studies it.

The teachers often remarked how valuable a learning activity they had found the group discussion. This was not only because they felt that they knew more science after the sessions than before, but because they had a greater awareness of those aspects of the science which they still did not understand. This metacognitive awareness was an important aspect of the discussions. In the course of completing the discussion activities the teachers typically discussed the content, limits and change in their understanding of the science at issue. The participants in the research learnt science, realised that they had learnt it and knew more precisely what they still needed to know.

I think my understanding, my own thinking, would be a lot tighter now even though I have a science background.

We believe that this was a function of the way the series of tasks were used. The same scientific ideas were revisited from multiple perspectives in successive tasks and this approach gave the participants in the research a variety of opportunities to represent and examine their understanding of any given scientific concept. The ease with which these representations could be compared facilitated the high level of metacognitive awareness.

The final three points are concerned with the way people come to the understandings described above. These ideas are referred to again in the concluding section which explores some of the problem the teachers had in constructing explanations in the three topic areas.

- **People get an overall idea about how things work, which fits with other things they know**

It is useful to get a general idea of how things work, because then any further detail has a place in which to fit. That general idea usually rests on simple commonsense ideas: what is inside what; what acts on what; whether something is a real object or substance; or is like something else such as an effect of one thing on another. Commonsense also provides helpful analogies, to explore or test an idea about how things might work.

Like a one way mirror that is something you can see through but can't see out - there is a different something on one side of that mirror - there has to be. It is the same thing with these gases, that from one side the sun can get through but whatever is on the other side can't get back out again. The gas must be formed in layers or is a mixture of something and what is on the bit facing the earth doesn't let the sun go back out.

- **Science is understood in this way through constructing pictures, images and analogies**

'Understanding science' is often thought of as knowing abstract laws, principles and facts. In our work, understanding science is a matter of seeing how to share its picture of a part of the world. The need is not to know facts about genes or rays or chemicals, but to imagine what they are like so as to see how they can work. The discussions generated a considerable amount of analogical type talk. Where specific analogies were used, they were most often employed to illustrate or summarise the teachers' thinking rather than as starting points for discussion.

The way I see it is like a puzzle. Inside each cell there is a photograph of the puzzle. Genes are parts of the jigsaw puzzle. The chemicals are like the colour on that jigsaw puzzle. So if there's something wrong there might *be a piece missing, or a piece not quite fitting properly. Which would be the defective gene. Gosh. I really understand this now.*

- **Commonsense thinking is a powerful and profound way of getting to grips with these pictures**

Science is usually sharply distinguished from commonsense, which is thought of as being of no value for understanding science. But in our work, people use all their practical daily knowledge of the world, sometimes to work out at quite a deep level what is going on in the science. People draw upon all their knowledge, including everyday experiences, to arrive at overall ideas which are broadly correct from a scientific point of view.

In police work they can identify a person from a few scraps of cells of that person, genetic fingerprinting from body fluids and cells they find at crimes. Which would indicate that every cell has the same information in it, otherwise you couldn't do that could you?

2 EXPLANATORY STORIES

The CHATTS project accumulated more than 2000 pages of transcript which were to be analysed. For most purposes the transcripts were too unwieldy and did not present the necessary information in a suitable form. For this reason we decided to condense the content of the transcripts into 'explanatory stories'.

An 'explanatory story' is composed of sections of the transcript where the group (or some members) focused for a time on a single non-contradictory account of a particular phenomenon to be explained or an area of concern. Such material was not always to be found in one continuous stretch of transcript. Thus these stories collated evidence relating to the same topic from different parts of a transcript and consisted of the precise words spoken about that topic by one or more members of the group, with however all personal marked removed. Within a story no indication is made as to which members of the group contributed. In this way sections of the transcript could be treated as the cognitive product of the group or part of the group. A story thus constituted an explanatory account of a topic and became the basic unit of analysis at this level.

In some cases a group would be discussing a topic (say the greenhouse effect), leave it for a while and then return and simply add to or explicate what had been said earlier. Relevant parts of these two sections of transcript would form a single story. If the group changed its mind about some part of the science, deciding say that the greenhouse effect and the ozone layer were two phenomena where before they had thought that they were one, a new story would be started. In cases where the group was debating two mutually exclusive accounts, for example plants making gases, or just storing and recycling them, two stories would be produced from a single piece of transcript.

The transcript of any one session typically produced a variety of stories relating to the different phenomenon under discussion and may also have contained two or more competing stories, produced either simultaneously or consecutively, where there was a divergence of views about the same phenomenon.

3 ADDITIONAL INFORMATION:

The CHATTS project has produced a series of seven working papers which explain its work in more detail. Their contents are:

Working Paper 1 describes the background to the CHATTS project, placing it in the wider context of research on the Public Understanding of Science.

Working Paper 2 describes the series of discussion activities that were designed as research tools for eliciting primary teachers' understandings of science in the CHATTS project.

Working Paper 3 is a collection of resource lists compiled as part of the research as reference material for teachers who had participated in CHATTS discussion sessions.

Working Paper 4 gives a theoretical perspective on explanation and its place in the CHATTS project.

Working Paper 5 describes the dimensions used in analysing the CHATTS data.

Working Paper 6 presents and discusses the findings of the CHATTS project.

Further information about the project and copies of the working paper (cost £1.50 each) are available from:

CHATTS, Department of Science Education, University of London Institute of Education, 20 Bedford Way, London WC1H 0AL