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ABSTRACT

The research is concerned with investigating children's understanding of physical, chemical, and biological changes while using an approach developed by the project Energy and Change. This project aimed to provide novel ways of teaching about the nature and direction of changes, in particular introducing ideas related to the Second Law of Thermodynamics in a way accessible to pupils aged 11 upwards. To accomplish this, the project developed an abstract picture language, through which the scientific story is told. An intensive study of the learning of a number of different groups of pupils was undertaken, based on records of their written work, observational notes of lessons, and small group interviews. The interviews were carried out at intervals throughout the teaching program in order to follow in a systematic way the development of pupil's ideas. This paper follows the progress of two groups of four 12-year-old pupils over a period of eight months. The abstract picture language and the teaching approach aim to provide a coherent and systematic account of the fundamental nature of all changes. The analysis reveals some of the issues which are involved in understanding the nature and causes of change and how this understanding can be fostered. (Contains 29 references.) (Author/YDS)

Pupils Reasoning about the Nature of Change Using an Abstract Picture Language.

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Pupils Reasoning About the Nature of Change Using an Abstract Picture Language

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Abstract

The research is concerned with investigating childrenís understanding of physical, chemical and biological changes while using an approach developed by the project ëEnergy and Changeí. This project aimed to provide novel ways of teaching about the nature and direction of changes, in particular introducing ideas related to the Second Law of Thermodynamics in a way accessible to pupils aged 11 upwards. To accomplish this, the project developed an abstract picture language, through which the scientific story is told. An intensive study of the learning of a number of different groups of pupils was undertaken, based on records of their written work, observational notes of lessons, and small group interviews. The interviews were carried out at intervals throughout the teaching programme in order to follow in a systematic way the development of pupilsí ideas. This paper follows the progress of two groups of four 12-year-old pupils over a period of eight months. The abstract picture language and the teaching approach aim to provide a coherent and systematic account of the fundamental nature of all changes. The analysis reveals some of the issues which are involved in understanding the nature and causes of change and how this understanding can be fostered.

Introduction

Increasing emphasis in science education has been placed on making fundamental and everyday issues, from pollution to global warming, accessible to a wider range of pupils. Essentially, pupils are expected to make sense of *processes of change* . Despite being of central importance to science, teachers and textbooks lack a way of explaining change that makes sense for this purpose. Essentially, what is needed are simple, everyday and coherent ways of talking about thermodynamic ideas which are accessible to school pupils. The research reported here is part of the evaluation of the teaching approach developed by the ëEnergy and Changeí project (Boohan & Ogborn, 1996; Boohan, 1996a). This novel approach introduces thermodynamic ideas in ways suitable for work at the lower secondary school. The approach aims to be intelligible to pupils, useful to teachers and scientifically consistent, so that it is useful to *all* pupils in helping them to understand the world, while those who later specialise in science can build on the ideas in a natural way.

Differences and the Second Law

The key idea in the approach is to pay attention to the *differences* which drive change. For example, air in a balloon tends to leak out because of a *pressure difference* - it continues to spread out until the pressure difference disappears. Pollution spreads out and mixes with the air in the atmosphere because of a *concentration difference* . Eventually the concentration difference disappears. Hot coffee cools because of a *temperature difference* . Energy spreads out into the surroundings, as it goes from hot to cold, until eventually the temperature difference disappears. Thus, differences tend to disappear because matter or energy or both become more spread out. This essentially simple idea is also powerful. We can use it to make sense of a wide range of phenomena from a hot cup of tea cooling, to the direction of chemical reactions and even to the complexity of life.

Many differences are expensive to obtain and may be able to do something for us. A frozen ice cube has to be specially made and can cool a drink. Pure water has to be specially provided and is important for life. Differences must be maintained if they are to be useful, and this may be difficult - ice easily melts, water easily becomes polluted.

How can we make differences? The hot water for the coffee was made hot by a hotter flame. Pure water can be made by distilling it, using a hot flame. Behind this is the idea that it takes a (bigger) difference to make a difference. Fuels are valuable because they can create a difference which drives a desirable change, such as heating a house or driving an engine. A difference is being used up to create another difference.

Warm rooms, plants or animals are all kept as they are, far from balance with the environment, by a heater, by sunlight, or by food. They do it by continually consuming differences, so as to maintain themselves. By being away from equilibrium they themselves constitute a difference which can cause other changes, as when we run around or when a flame heats a kettle.

How does the idea of ëdifferences driving changeí relate to more conventional scientific explanations for ëwhy things happení? The question is addressed by using ideas related to the Second Law of Thermodynamics. In scientific terms we would say that for a spontaneous change, the total entropy of the system and surroundings increases until it reaches a *maximum* . The idea of ëdifferenceí therefore relates to the concept of *negative* entropy; the key idea is that differences drive change because differences tend to *decrease* (which is a way to say that entropy tends to *increase*). Another way of looking at this is to say that the informal notion of ëdifferencesí corresponds to the scientific concept of free energy - both tend to be ëused upí during a spontaneous change (Ogborn, 1990).

Second Law ideas are traditionally not paid much attention in school science, at least until more advanced work. The Second Law has a reputation of being complex and difficult to understand. In addition, there has been a tendency not to pay much attention to research into childrenís ideas in this area, though work suggests that students tend to reason about the nature of changes in everyday terms rather than within a scientific framework (Duit & Kesidou, 1988). This account in terms of differences opens up the possibility of dealing with these ideas starting with pupils in the lower secondary school (ages 11 and upwards).

An abstract picture language

To make these ideas intelligible to pupils the project developed a range of *abstract pictures* . The intention was to provide a way for children to compare very different examples, such as evaporation and melting, so as to see fundamental similarities and contrasts between these changes in what is happening to the particles and the associated energy. The abstract pictures are a tool to help pupils represent and discuss the story about differences and change in a wide variety of processes. Some of these pictures may appear somewhat daunting at first, but we have found that pupils are quickly able to become familiar with them, and are stimulated into a good level of discussion.

The picture language was originally conceived and developed in the context of the classroom, working alongside teachers and pupils in the beginning of secondary school (ages 11-14). Moreover, the picture language is designed to be consistent with the later, more orthodox, language of thermodynamics. The rationale for the design and development has been described elsewhere (Boohan, 1996b). Typically an activity consists of a set of changes and a set of relevant abstract pictures, and pupils are asked to make appropriate matches. What is important is not so much the matching itself, but the discussion which is stimulated during the process of matching and when pupils are challenged by the teacher and by other pupils about their choices.

Some early kinds of pictures, showing changes to matter and energy, are represented in Figure 1. In each of these boxes, the top picture represents ëbeforeí and the bottom picture represents ëafterí, so time goes from top to bottom. Since discussion is a central feature of the activities, pupils are introduced to ways of talking about these abstract pictures. For example, in Figure 1(a), matter is shown ëspreading outí (as a concentration difference disappears); in Figure 1(b) the opposite change is shown in which the particles are ëbunching togetherí (a concentration difference is being created). Similar kinds of pictures can be used to show particles ëmixingí and ëun-mixingí or ëjoiningí and ësplittingí. Figure 1(c), shows energy flow due to a temperature difference - the top picture shows a system (dark shading) which is warmer than the surroundings (light shading), and an energy flow from system to surroundings. The bottom picture shows that eventually, the temperature difference disappears. Figure 1(d) shows a system becoming warmer than its surroundings.

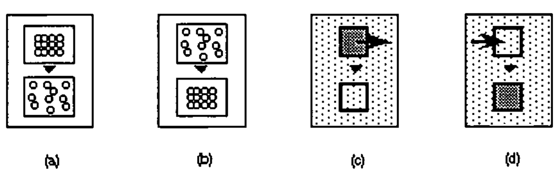

Figure 1. ëSpreading outí and ëbunching togetherí

For younger pupils, there is a wide range of different pictures which are able to represent specific kinds of change. Later, they will be introduced to the idea that some changes ëjust happen by themselvesí (they are spontaneous), while other change do not ëjust happení but need to be driven by another change. For older pupils, then, the approach becomes more abstract, using pictures which represent relatively few *fundamental* kinds of change. The pictures representing *spontaneous* changes (changes which ëjust happen by themselvesí) are shown in Figure 2. The downward arrow on the box indicates spontaneous change - the corresponding non-spontaneous changes are represented with an upward arrow on the top of the box.

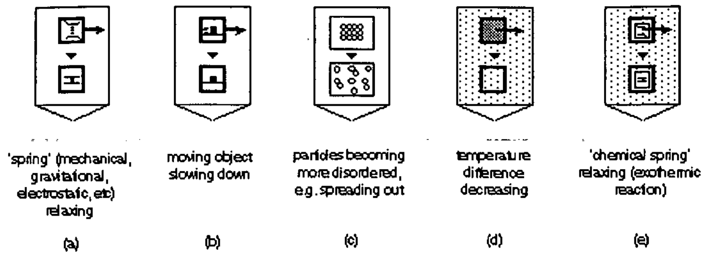

Figure 2. Fundamental kinds of spontaneous change.

Such changes represented in Figure 2 can drive changes which are non-spontaneous, and examples of these are shown in Figure 3. (A distinction is made in these pictures between changes in which one system is coupled to and drives another, as in Figure 3(a), and changes which take place within a single system, as in Figure 3(b).)

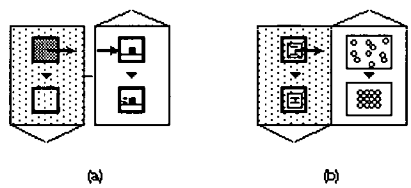

Figure 3. Coupled changes.

Here, in Figure 3(a), energy spreading out due to a temperature difference is being used to *drive a change* in which something is made to start moving - this could for example represent a steam engine. In Figure 3(b), energy spreading out from an exothermic chemical change is driving a change in which particles become more ordered - this could for example represent the crystallisation of copper sulphate.

The concept of energy in school science

An understanding of why things change is clearly of fundamental importance in science. How is it currently taught in schools? ëEnergy is what makes things happení is a fairly typical statement which could be found in many school science textbooks. It sounds plausible, but it is wrong, and has led to much confusion. A flame heats a pan of water, not because the flame ëhas a lot of energyí, but because the energy in the flame is more concentrated than the energy in the water (i.e. it is hotter). It is this difference which drives the flow of energy.

In addition, the focus in many school textbooks on learning about ëforms of energyí may not be helpful in developing an understanding of the concept. To say that a car engine converts chemical energy in petrol to kinetic energy adds little to our understanding of the fundamental nature of the change. And while electric fires are said to ëconvert electrical energy to heat energyí, what do refrigerators do? We cannot say they convert electrical energy into ëcold energyí! A ëdifferencesí approach accounts for such changes more easily - electric fires and refrigerators create temperature differences which do not arise by themselves, but are created by a difference being used up in a power station.

Thus, the difficulty with teaching about ëwhy things changeí is that the term ëenergyí has been inappropriately recruited as a cause of change. Indeed, in both its everyday use and the way it is used in many school textbooks, the term is much closer in meaning to the scientific concept of ëfree energyí than the concept of ëenergyí. This has caused much confusion and stimulated a great deal of debate about these issues (for example, Duit, 1981; Schmid, 1982; Warren, 1982; Marx, 1983; Driver & Millar, 1986; Ellse, 1988; Ross, 1988; Solomon, 1992). Research into childrenís ideas about energy suggests that their starting point is that energy represents a power to act which is used up and may be refreshed (for example, Watts, 1983; Brook & Driver, 1984; Solomon, 1984). Indeed, we do use up *something* when we burn some coal in a power station or run a race, but this is not energy, since it is conserved in every change. However, differences are used up during changes, and they do not spontaneously appear by themselves, but need to be created from other differences.

It should be clear that this ëdifferencesí approach to teaching about why things change is not something which is confined to a topic called ëenergyí. The ideas can be addressed throughout the whole science curriculum, and can form the basis of a consistent story about change which can be developed across the whole age range.

About the Research

One of the principal aims of the research was to see whether, over a period of time, pupils using the project materials began to change their thinking. Would they shift from seeing processes of physical and chemical change as all very different from one another, perhaps impressed by their different appearances, to seeing basic similarities between them? And would they focus more on differences, especially of concentration and temperature? Did the pictures and language used to describe them help in all this? These were the main research questions.

Design of the Research

The research was carried out in two phases. The first phase had an exploratory character and was mainly informed by the needs of the project to investigate the way children make sense and use abstract pictorial representations (Stylianidou, 1995). In the second phase the influence of the novel teaching approach on childrenís ideas about processes of change and their causes was monitored more systematically and over a longer period. The design of the second phase was based on the experience and preliminary analysis of the first phase. The work took place in a secondary school which was integrating the teaching material produced by the ëEnergy and Changeí project in their lower secondary science curriculum. The school is an inner-city London state school for pupils aged 11-18. The pupils are taught in mixed-ability classes. Over a period of eight months, two classes of children of 11-13 years of age and their teachers were observed using the projectís materials in their science lessons.

The Projectís Materials Used for the Research

The projectís materials are not a course in themselves, but are designed to be used alongside schools existing resources. It is intended that the ideas should be developed throughout the whole period of secondary school, though because of the relatively short duration of the project it was not possible in the trials for older pupils to build on work in earlier years. Most of the trials took place over the course of one academic year.

The research reported here focused on the effects of the use of the project's materials introduced in three topics studied by a Year 8 class (12-13 year-olds) - *Substances* , *Energy* and *Food and Fuels* . These topics from the school's scheme of work were chosen by the project because they covered a range of sciences (biology, chemistry and physics) and provided many opportunities for thermodynamic ideas. They provided the context for some of the projects key ideas, related to particles, physical and chemical change, energy flows and spontaneity, to be introduced.

Because of the time constraints of the trials, these Year 8 pupils had not done the earlier project activities intended for pupils in Year 7 (11-12 year-olds). These are concerned with processes of dissolving, mixing, crystallisation, diffusion and changes of state. These materials invite pupils to pay attention to differences in concentration and identify matter spreading out and bunching together, mixing and ëun-mixingí; to pay attention to existing differences in temperature and identify their disappearance; and finally to pay attention to processes that happen easily but are more difficult to reverse. The use of these materials in three topics with a Year 7 class was also investigated and this has been reported elsewhere (Stylianidou, 1997a, 1997b).

The projectís materials and class activities for the Year 8 class are concerned with the particulate nature of matter and the changes to it; they invite pupils to pay attention to changes where the particles are ëjoiningí or ësplittingí and to differentiate these from changes where particles are mixing or ëun-mixingí. They also require from them to look for temperature differences and to identify energy flows due to temperature differences. Energy flows would also be seen as flowing from stores of concentrated energy such as fuel-oxygen systems. These stores are presented as stretched ëchemical springsí; their release is accompanied by an energy flow. Furthermore, pupils are asked to think about spontaneous and non-spontaneous changes, to consider that some changes just happen by themselves, while some do not; for a non-spontaneous change to happen there has to be a spontaneous one to drive it. The sequence of topics was planned with the assumption that later activities would draw on knowledge already gained from earlier ones. So, for example in Year 8 the topic *Food and Fuels* was introduced after those of *Substances* and *Energy* , as the discussion of burning food and fuels require some understanding of chemical change and energy flows, introduced in the first two topics.

Data Collected

The data collected in this phase of the research consist of:

ï interviews carried out with the pupils

ï observational records of the science lessons attended for both classes

ï copies of all the pupilsí written assignments and tests

ï copies of the teachersí completed evaluation forms for each one of the projectís activities they used in the classroom

ï interviews with all the science teachers of the school ï questionnaires administered to teachers who had attended one-day in-service training sessions about the project

Four interviews were conducted with all the pupils of each class in groups of four, aimed at detecting the effects of the systematic use of the projectís materials. The first interviews were carried out before the projectís materials were used, with subsequent interviews after each of the three topics. They were designed in order to focus on some particular questions. Does the matching of real world situations to abstract pictorial representations help to draw pupilsí attention to the more generalised features of the changes? And furthermore, do they consider these features when they reason about similarities and differences between different changes? The analysis of this material for the Year 8 class forms the focus of this paper.

The pupilsí interviews on their own, however, would not suffice to meet the research objectives. Information was required about the kinds of experiences that children had in the classroom, and about how the projectís activities were actually used by the teachers and pupils. Detailed observational notes were kept on each lesson attended, and copies of all the written assignments and tests the pupils did as part of the three science topics were collected. The analysis of this material for the Year 8 class has been reported elsewhere (Stylianidou & Boohan, 1998).

Finally, the role of the teachers in the teaching process as well as their professional experience was not ignored, and the views of those involved were elicited in questionnaires and in interviews.

Pupilsí interviews

As mentioned above the small group interviews of pupils were carried out at intervals throughout the teaching programme in order to follow in a systematic way the development of their ideas. They were designed to encourage pupils to talk about fundamental aspects of change using the ideas and terms developed by the project. Each interview consisted of three activities.

In the first activity pupils were presented with a set of situations; they had to pair each situation in turn with the one they considered most similar. This activity provided information about what features of the changes children pay attention to spontaneously when seeing similarities, as well as information about how children think of particular changes.

In the second activity they were asked to match the same situations to abstract pictures and explain their choices. This activity helped to address the question of how well the children managed to use the terms and ideas introduced by the project to describe what is happening in a variety of familiar and less familiar changes.

Finally, after the pupils had matched all the situations, they were asked to explicate the similarities and differences between certain pairs of situations chosen carefully to address issues of importance to the research. The question here was: How well and at what level of generalisation did the children manage comparisons of different physical and chemical changes with the aid of abstract pictures? The set of situations and the set of abstract pictures used were different for every interview and depended on the topic the pupils had previously completed.

This paper follows the progress of two groups of four 12-year-old pupils, drawing on their performance in the interviews. More specifically, it discusses how well pupils managed to account for a variety of physical and chemical changes in terms of the matter and energy changes involved. The discussion is based on the explanations that the pupils gave for matching these changes to the relevant abstract pictures, and on how these explanations and choices varied in subsequent interviews.

Changes to Matter

One of the themes of the projectís materials used with this Year 8 class is concerned with the particulate nature of matter and the changes to it. Some examples of the kinds of pictures used in the activities are shown in Figure 4(a). Here the convention is that different substances are represented by particles of different shading, so while the first picture shows a change in which a new substance is being formed, the second represents mixing. To these and similar pictures, pupils are asked to match changes such as ëwashing dirt off your handsí, ëusing bleach on clothingí or ëputting Alka Seltzer into waterí.

Later, pupils are introduced to the idea that new substances are formed when the particles join together in new ways. They are asked to decide whether changes such as ëpurifying waterí or ëheating copperí can be considered as examples of ëjoiningí, ësplittingí, ëmixingí, or ëun-mixingí. The representations of ëjoiningí and ëmixingí are shown in Figure 4(b). The representations of ësplittingí and ëun-mixingí are given by reversing the order of the pictures in Figure 4(b).

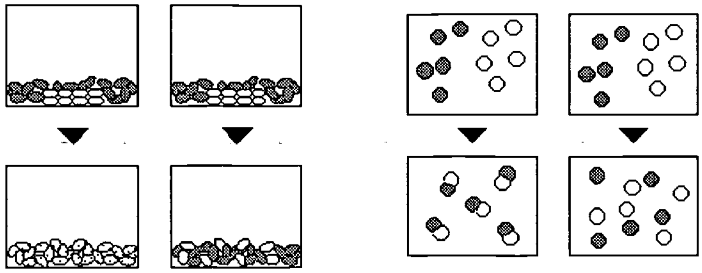

Figure 4. Particles and changes.

How did the pupils cope with these ideas? Not surprisingly, all the pupils found it difficult to identify changes of substance correctly and thus to distinguish the chemical from the physical changes. The difficulties they encountered have also been identified by several other studies, for example Schollum (1981) reported in Briggs and Holding (1986). However, the use of the pictures encouraged them to identify relevant features and make explicit to themselves the difficulties involved in classifying the changes.

Joining, Splitting, Mixing and Un-mixing

The abstract pictures of ëjoiningí, ësplittingí ëmixingí and ëun-mixingí were included by design in the second interview in conjunction with the situations ëa snowman meltingí, ëa car rustingí ëextracting copper by electrolysing copper sulphate solutioní, ëcleaning a paint brush in wateri, ëa babyís bones growingí, ëpurifying wateri, ëputting Alka Seltzer in wateri and ëmetal foil being crumpled upí.

Rusting was a change the pupils had previously discussed in their lessons, and as a result ëa car rustingí was successfully matched to the ëjoiningí picture by both groups of pupils. However, the identification of the reactants and product of the reaction was not always so desirable. Whereas in the second group the pupils identified the two reactant substances, iron and oxygen, and they explicitly acknowledged that the product rust is a new substance, in the first group this identification was not only incorrect - the rust was seen as joining on to the car by one pupil - but was also at the level of object rather than at that of substance. That is, the air and the car were said to join and turn into rust.

For the change ëa babyís bones growingí, the pupils lacked knowledge about the reactant substances and the processes involved. Not unexpectedly, therefore, this led them to give similar kinds of descriptions in terms of objects, though they explicitly acknowledged that the product of this ëjoiningí process is a new substance.

The intended match for ëextracting copper by electrolysing copper sulphate solutioní, a change the pupils had done as a practical activity in their lessons, was the ësplittingí picture. All the pupils of the first group agreed right from the beginning with this match, though still as before found difficulty in naming the substances which participated in the reaction. However, the pupils of the second group preferred to match it to the ëjoiningí picture, having apparently mistaken the change of colour observed on the carbon electrodes due to the copper deposit to be a ëjoiningí change:

> *The blue stuff, copper sulphate, and electronic or something I think, join together and make a new substance, copper, copper colour.*

The pupilsí use of the term ësplittingí most of the time was not as they had been taught. By using it to describe what is happening in ëcleaning a paintbrush in wateri and in ëpurifying wateri it was clear that some children considered it as a synonym of ëseparatingí or ëun-mixingí, whereas the teaching materials had intended it to be used strictly for chemical changes. Moreover, they seemed to favour, as was the case with ëjoiningí, a macroscopic use of the term where objects and not substances are seen as splitting. It is worth also mentioning that an intense discussion took place between two pupils as to whether ëa snowman meltingí is a ësplittingí change. The pupil who won the argument maintained firmly that

> *...when itís melted, the water goes away, and the cold air or whatever the other substance is, goes away too, so itís being splitted up.*

because

> *...ice is not just water. If it was just water, you couldíve drunk it, but it contains something.*

She may not have managed to fully convince the other three girls in group one, they however accepted her explanation as possible and kept the match, although they had the option of choosing a picture representing ëno change of substanceí.

The same idea, namely that ice is something more than water, or in other words that water joins with something (oxygen was a tentative suggestion by one of the pupils of the second group) to make ice, was also offered as a justification in group two for matching ëa snowman meltingí to the ëjoiningí picture. This time however, the counter argument that water and ice are one and the same substance was stronger and survived.

The picture showing ëmixingí was chosen as a match for the situations ëcleaning a paint brush in waterí and ëputting Alka Seltzer in waterí by all pupils of the first group without exception. The second change had repeatedly appeared in the projectís classroom activities and its match had presented problems to the pupils as they had found it difficult to differentiate between changes of dissolving and chemical changes between a solid and a liquid. Some pupils tended to look for changes in the colour of the substances in order to decide whether a chemical reaction had taken place, others seemed to believe than if something dissolves it makes a new substance. This latter belief has also been reported by Prieto, Blanco and Rodriguez (1989) to be shared by some students aged 11-14 years. In the context of these misconceptions we found it interesting that although the match of the change ëputting Alka Seltzer in waterí was not appropriate, in his/her explanation the pupil accounted for the process of ëmixingí in rather desirable terms:

> *Theyíre mixing, they are not becoming a new substance, theyíre just mixing. Theyíre next to each other.*

Moreover, it is reasonable to assert that the production of an explanation like this was aided by the existence of the relevant abstract picture.

The pupilsí struggle to differentiate between physical and chemical change was also evidenced in the reasoning of one pupil in the process of explaining why the change involved in ëpurifying waterí was one of ëun-mixingí and not of ësplittingí. Her reasoning was not based on any scientific notions; she rather used as criterion what s/he perceived as the physical distance of the products of the change:

> *Itís separated, itís not splitting, because splitting means you split it in the same container. But itís not going to be in the same container - oneís going to the filter paper and one is going here. [...] And unmixing does not mean in the same container, but this one does.*

The situations ëcleaning a paint brush in waterí and ëpurifying waterí were also matched appropriately (to the abstract picture of ëun-mixingí) by the second group of pupils. Moreover, their use of the terms ëmixingí and ëun-mixingí appeared quite sophisticated and desirable. In ëpurifying waterí for example, although the names of the substances may not have been again known to the pupils, they preferred to talk about *"solid and liquid"* first mixing and then separating, that is they preferred to name the participants at a generic level than at a particular object level.

To conclude, whereas on the whole the pupils decided on appropriate pictures as matches for the situations they were given, there is little evidence from their explanations that they either managed to account for or that they differentiated successfully between physical and chemical change. Having said this however, it appears also clear to us that the need for this differentiation was something that they had become conscious of and sometimes partially managed.

Temperature Differences and Energy Flows

Another section of the materials used with the Year 8 class aims to teach pupils to look for temperature differences and identify energy flows due to temperature differences. Examples of the kinds of pictures used in the activities are shown in Figure 5. The top row shows some ëbeforeí pictures and the bottom row shows some ëafterí pictures, which pupils are asked to use to represent changes such as ëfrozen peas left in a roomí or ëplates put in hot washing-up waterí.

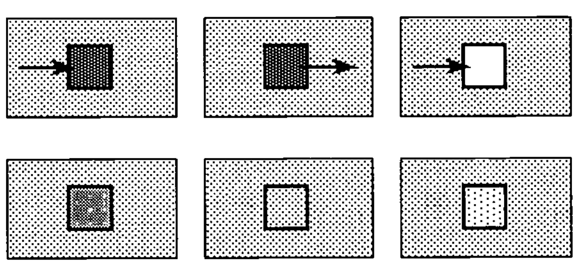

Figure 5. Temperature differences and energy flows.

A later activity is concerned with the idea that insulation acts as a barrier to energy flow, as pupils consider matches between pairs of pictures and insulated/un-insulated situations, for example, ëfrozen food left in a roomí and ëfrozen food wrapped in newspaperí, represented in Figure 6. Dark shading represents high temperature, and can be thought of as a high concentration of energy.

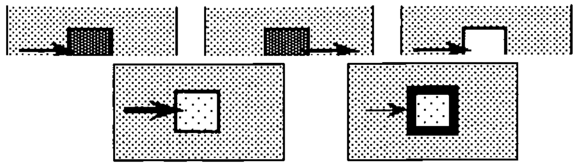

Figure 6. Insulation.

In the first interview before the pupils had met any of the abstract pictures they were asked to choose among a given set of phrases to apply to the situations presented to them. As can be expected the use of the expression ëenergy spreads outí was not very sophisticated. Energy was treated as a fuel-like localised entity which is needed for changes to occur and which gets destroyed in the process. Moreover, its spreading out was seen as occurring in space usually accompanying the spreading out of the substance which contained it. That is, the pupils at the beginning used the metaphoric expression ëenergy spreads outí with its literal meaning; the emphasis was more on the changing object rather that on the flow of energy. This is very explicit in the following quotation about ëwood burningí:

> *The energy of the fire spreads out and eventually it dies out. All the energy is going. The energy is the wood. The wood begins to fade, begins to get shorter, and energy fades away.*

or when it was explained that ëenergy spreads outí when a plant grows because:

> *The sun spreads all over the thing.*

Having said this, energy was not only seen as spreading out in ëa plant growingí. The second group of pupils, otherwise unsure about whether and how energy was involved in most of the changes in the first interview, seemed definite that *"energy is making the plant grow more"* and thus it also ëbecomes more concentratedí.

Four months later, in the third interview, the progress was evident. Although still associated sometimes with material changes in concentration, now energy was seen as flowing and almost always as accompanying temperature changes. ëConcentrated energyí, a term used by the project as equivalent to temperature, was seen to reside in hot things but cold things were said to have no energy (rather than ëdilutedí energy). Finally, a thermal change was often perceived to end when the system reached the temperature of its surroundings.

The picture ëenergy spreads outí was kept as a match for five out of the eight situations in the first group, namely for ëan electric iron cools down after being switched offí, for ëwater vapour forms clouds and it rainsí, for a candle burning labelled ëmelting wax, for ësmoke filling the air over a cityí and for ëan explosioní; for all five there were acceptable arguments for the match. As mentioned before energy was often seen behaving as a substance; in the following quotation about an electric iron which cools down when it is switched off, it was suggested that the energy itself cools down to the temperature of its surroundings:

> *The concentrated energy which is in the iron, cools down and then spreads out and goes to room temperature.*

Interestingly, in the second group the discussion of this situation also revolved around the ësubstantialí nature of heat. Three out of the four pupils had matched the situation to both the picture showing energy spreading out due to temperature differences and to this showing particles spreading out. For them, the second picture represented *"the warm substance"* which spreads out. The fourth pupil however, pointed out and seemed to win the argument that *"heat is the energy, not the substance"*. This confusion is evocative of the difficulties with the teaching of energy via heat exchanges (Brook, Briggs, Bell, & Driver, 1984; Engel Clough & Driver, 1985; Erickson, 1979; Mak & Young, 1987; Summers, 1983).

The necessity for the temperatures of the system and its surroundings to be described as becoming more equal as a result of the change, which should be considered as desirable and as largely imposed by the symbolism of the abstract pictures, was clearly felt by some pupils. We see the following pupil in group one struggling to contain this necessity in her account of ëwater vapour forms cloud and it rainsí:

> *The concentrated energy is in the clouds; when it is really really concentrated it rains, and then when it rains it becomes the same sort of temperature, [...] it comes whatever temperature the weather is..., you know..., the surroundings is.*

The use of the picture ëenergy becomes concentratedí evolved on similar lines. The picture was kept by the first group as a match for the situations ëwarming your hands by the radiatorí - its intended match - and ëyour body making extra fatí. This time the conventions of the abstract picture showing a temperature difference being created were not so rigorously applied to the situations. It is interesting how a pupil constructed an explanation for a system which was seen to warm up due to an energy flow from the hotter surroundings by combining the use of the ëenergy becomes concentratedí picture, which shows the system at the beginning at equilibrium with its surroundings, but afterwards hotter than them due to an in-flow of energy, with a ëspreading outí explanation:

> *Your hands are very cold and when you put them near the radiator, the radiator is very concentrated and then it gets, it makes it hot, warm which makes your hands more concentrated. The heat of the radiator is all like spreading around and then it gets to your hand, it doesnít exactly like bunch together, but it spreads around sort of thing, but it makes your hand get hotter.*

In the second group of pupils the same abstract picture was finally kept as a match for the changes ëwater vapour forms clouds and it rainsí and ëyour body making extra fatí. In the first case, the pupils felt compelled to choose this picture since they identified the necessity of an inwards flow of energy for vapour to ëbunch togetherí. They, however, could not come up (at the start at least) in their accounts of the situation with any of the temperature changes also depicted in the pictures. In the following extract, it becomes obvious how in order to attempt to satisfy these conventions the pupils distorted their explanation of what is happening when water vapour forms clouds and it rains:

> *P1: But something gives the energy to get together - isnít it-, something gives the energy. It doesnít get warmer, it stays the same temperature, but something gives the energy gives to the cloud to get together.*
>
> *[...]*
>
> *P1: Maybe the cloud is cooler than the surroundings and...*
>
> *P2: Yeah... and something is giving the energy and making...*
>
> *P1: ...the surroundings giving the energy to make it to get together...*
>
> *P2: Yes, and then makes it hot. Something like that.*

Despite the fact that neither the match nor the explanation were correct, we find that in the above dialogue pupils are trying to use important and subtle ideas. They rather instinctively maintained that a ëbunching togetherí process needs to be driven and with the aid of the pictures seemed to make the implicit acknowledgement (expressed explicitly rather clumsily) that the driving process should involve somehow a destruction of a temperature difference.

A similar situation arose in the discussion of the change ëyour body making extra fatí. Only now the discussion was more complicated and less conclusive since food was seen as giving energy to the body, but the body as remaining at a temperature difference from its surroundings.

Finally in the fourth interview, a month after the third one, the pupils used the same pictures (but now with labels ëenergy escapesí and ëenergy is storedí) this time only in relation to temperature changes. This could be attributed to some combination of three reasons; one could be that the pupils had got more familiar with the use of these pictures; second, that the labels ëenergy spreads outí and ëenergy becomes concentratedí distracted the pupils into reasoning about concentration changes, and thus the change of these labels to ëenergy escapesí and ëenergy is storedí resulted in the elimination of this less desirable reasoning; and third, that the existence of the other set of pictures in this interview which showed energy flows due to chemical potential differences helped make clearer the application of the first kind.

Another difference in the childrenís use of these pictures compared with the third interview was that more emphasis was clearly now put on the flow of energy which was seen as triggering a temperature change and less on the temperature of the surroundings, mention of which was absent. In the case of ëice forming on a pondí the out-flow of energy was seen as triggering the formation of ice, that is, a change of state;

> *Because the pond is hot, and what is happening is that the energy from the pond is going out and the ice, the cold ice which has got no energy inside is going to form on the pond.*

The picture ëenergy escapesí was also chosen correctly by group one as a match for the situation ëa hot bath cools downí. All situations matched to this picture were also matched to the ëit just happens by itselfí picture, that is, to the picture representing a spontaneous process, again as desired.

The second group of pupils chose the picture ëenergy escapesí for the situations ëice forming on a pondí, ëacid rain eroding a stone statueí and ëa hot bath cools downí. Interestingly, in all three cases the system seen as giving out energy was said explicitly or implicitly to remain with no energy in the ëafterí instance. In ëice forming on a pondí *"the water was a bit warm and it gives out all the energy it has and cools down"* ; in ëacid rain eroding a stone statueí acid rain *"gives out energy to the stone and destroys it and then it doesnít have any"* ; and in ëa hot bath cools downí *"the water is hot..., and the energy goes out and it cools down"* . This idea is consistent with a view of energy as a localised entity, also identified elsewhere.

The picture ëenergy is storedí was chosen by group one for the situation ëwood burningí, seen as becoming warmer. The process of the temperature change was identified, with fire being its agent. There was no reference to an energy flow. However, in the third activity of the interview it was clearly stated that in ëwood burningí energy was seen as both flowing in and out of the system; this statement was unfortunately not elaborated further.

In the second group, the picture was kept as a match only for the situation ërunning and using up foodí since ëusing up foodí was understood as ëeating foodí and energy was identified as flowing from the food to the human body. This was an inappropriate match. The picture was also chosen by three out of the four pupils for the change ëwood burningí; fire was seen as providing energy to the wood and as creating a temperature difference between the wood and its surroundings. However, the observed outward (from the wood) flow of energy was eventually thought of as more important and the picture was eventually abandoned.

Summing up, it is necessary to note that despite the improvement observed in the childrenís use of the pictures of ëenergy transferí their notion of energy was not clearly differentiated from other concepts. The following quotations suggested this:

(charging a car battery)

That one needs energy or whatever, the power to go inside.

The energy, the force, whatever goes inside it [spreads out].

(pulling a catapult to get ready to fire a stone)

The energy spreads out from the thing. You hold the string so the energy is..., you know..., being pulled.

A similar finding has also been reported by Duit (1984). In a comparative study carried out in the Philippines and former West Germany, students were asked to define or describe the meaning of energy, work, power and force and then to give examples for each one of them, both before and after physics instruction. The results suggested that students do not differentiate in meaning between the terms force, power and energy and this confusion among all four terms is apparent in many students even after physics teaching.

Moreover, the conceptualisation of energy as a substance-like thing which gets used up, seemed to be powerful and resistant to change; its traces were easily detected even in the last interview: ëRunning and using up foodí and ëwood burningí were said to be similar because *"they both use up energy"* .

Stores of concentrated energy and energy flows

In the project materials energy is also shown as flowing from stores of concentrated energy such as fuel-oxygen systems. Such systems are represented as a ëchemical springí. Thus, one way that energy could be stored would be by making something hot as in Figure 7(a), for example using an electrical supply connected to a heating coil to make some water hot. However, the same electrical supply could be used to electrolyse the water, splitting the water into hydrogen and oxygen. Making this hydrogen-oxygen system can be thought of as ëstretching a chemical springí, as in Figure 7(b); when the two gases react together again, the ëspring relaxesí and energy is released.

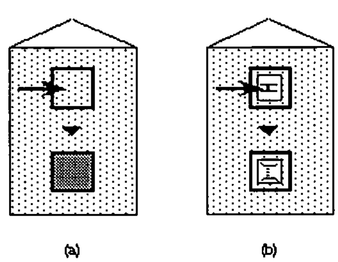

Figure 7. Ways of storing energy

The pictures of chemical springs (Figure 7(b) and its reverse) were introduced to the pupils during the last two lessons of the topic *Food and Fuels* . These are difficult pictures with new conventions (the stretched and released spring conventions to show chemical potential differences) representing difficult ideas. The space of two lessons was certainly not enough for the pupils to understand and familiarise themselves with the use of these pictures. Moreover, the interview that followed seemed to stretch this inadequate familiarisation to the limits. The abstract pictures used in this interview included the ones in Figure 7 and their reverse, with one small difference. Those pictures did not have the upward (or downward) big arrow which depicts the non-spontaneity (or spontaneity) of the process; the pupils had to reason about whether a change ëjust happens by itselfí or not, by separately choosing the right arrow and explaining their choice.

Right from the start of the interview the pupils asked the interviewer to explain to them again what the pictures of chemical springs showed. This was repeated several times in the course of the interview. Also in order to minimise the level of disagreement among the group, for each situation the pupils were asked to agree all together before making their individual choice of picture on whether energy was going out or in. In this way the interviewer helped them focus on at maximum two of the energy pictures at a time for each situation, so as to facilitate their choice.

Despite all these difficulties the two ënovelí pictures were matched appropriately by the first group of pupils; the ëenergy escapes IIí picture (which is like the reverse of the picture in Figure 7(b)) to the change ërunning and using up foodí and the ëenergy is stored IIí picture (like Figure 7(b)) to the changes ëa plant growingí, ëcharging a car batteryí and ëpulling a catapult to get ready to fire a stoneí. However, from the explanations the pupils gave for their matches it is clear that they understood little of what was happening. Having to face pictures they could hardly comprehend they resorted to inventing interpretations for them based on their perceptual characteristics; in other words they attempted to interpret the abstract pictures superficially. An illustrative example of this can be seen in the following quotation. The pupils had successfully matched the change ërunning and using up foodí to the picture of ëenergy escapes IIí, but explained:

> *I think like say you put food in your mouth, so like your stomach sort of expands sort of thing, and then youíre jogging you use it all up and it like doesnít go small again but it closes up ready for another portion of food to come down and then it opens back up again. It uses the energy, it shuts back up.*

The movements of the stomach above were mapped on the picture showing a spring first stretched and then at its normal size.

Having said this, the pupils in the second group managed a much more sophisticated explanation for the same change attempting to combine the idea of an outward energy flow with that of a ëjoiningí chemical reaction:

> *The energy goes out... and he runs and the particles join again.*

or in another pupilís words:

> *When you run the particles force themselves to get together and the energy goes out.*

Similarly, the pupils of the same group acknowledged after some prompting from the interviewer that in ëwood burningí oxygen and wood join together and energy spreads out. Moreover, on this basis further on in the interview the pupils reasoned that the two situations ërunning and using up foodí and ëwood burningí are similar because *"they give out energy"* .

The match all pupils got correct without much difficulty was this of the situation ëpulling a catapult to fire a stoneí to the picture ëenergy is stored IIí. They easily reasoned that in this change energy flows into the system and thus get stored.

Moreover, the matching of the situations ëa plant growingí and ëcharging a car batteryí gave rise to very stimulating and interesting discussions among the pupils of the second group. In the case of ëa plant growingí, and starting from the assertion that a plant needs energy to grow, thus there is a flow of energy into the system, their reasoning evolved as following:

> *We are storing energy in the plant by making it bigger, but it doesnít get warm. ... Maybe by splitting the particles itís making it grow bigger. ... In picture No 5* [ëenergy is stored IIí] *first the particles are together and then the energy goes in and splits the particles into parts and it stores itself in the particles, between it. ... But what could be the particles? ... Itís not cells, is it - the particles?*

Despite their lack of knowledge about the participants and processes of the change, which forbade them to arrive at a more accurate and precise explanation, with the aid of the abstract pictures the pupils managed to formulate a quite sophisticated explanation at a high level of abstraction. Indeed, in their account of the situation ëcharging a car batteryí the pupils themselves could not have put it in better words:

> *It doesnít matter what sort of particles, it is the energy goes in the particles and splits them up to store itself. ... Itís like that plant growing...*

Interestingly and appropriately also almost always a choice of the ëenergy escapes IIí picture was combined with the choice of the ëit just happens by itselfí picture and equivalently the choice of the ëenergy is stored IIí picture was combined with the choice of the ëit needs something to make it happení picture.

On the whole, it can be said that the idea of a ëchemical springí proved to be the most challenging for the pupils. Nevertheless, it was not totally inaccessible; most of the pupils managed to make some sensible use of them in their explanations.

Spontaneity and reversibility

ëIt (just) happens by itselfí, ësomeone makes it happení or ëit needs something to make it happení or ëit doesnít just happen by itselfí; ëit is easy to reverse the changeí: All these phrases concern the issue of reversibility, the first four more particularly the issue of spontaneity of a change. The ideas behind the expressions ëit happens by itselfí and ësomeone makes it happení also appear in the projectís materials but with the altered expressions ëit just happens by itselfí and ëit doesnít just happen by itselfí. This alteration which is more prominent in the expression intended to describe the non-spontaneous changes arose partly from the awareness gained from the study of the pupilsí use of the expression ësomeone makes it happení in the first interview. This expression seemed to lead the pupils to look for the possible presence of a human agent in a change, something which is not always helpful in encouraging thermodynamic thinking.

In other words, what children seemed to imply at the start is that every change needs suitable circumstances in order to occur; no change was thought of as happening ëby itselfí. A human action was mostly seen as necessary in order to create these suitable circumstances. So, for a plant to grow the pupils reasoned that *"someone has to water it"* , and for wood to burn that *"someone has to light a fire"* , conditions indeed necessary from a commonsense perspective for the changes to happen. The same kind of thinking however also led the pupils to doubt whether a hot bath cools down by itself since someone has to put the hot water in the bath in the first place.

The same line of reasoning was pursued in the second interview, despite the fact that only the phrase ëit happens by itselfí was used there as a prompt. As a consequence the changes ëputting Alka Seltzer in waterí and ëcleaning a paintbrush in waterí were said not to happen by themselves because

> *Someone should drop the thing [Alka Seltzer] to dissolve it, and this [cleaning a paintbrush in water] you have to use your hands, a human hand to brush it.*

Both changes were intended to be seen as spontaneous changes.

Finally, the corresponding pictures ëit just happens by itselfí and ëit needs something to make it happení were put to use only in the fourth interview, after having being introduced in the preceding topic of *Food and Fuels* . This time the pupilsí usage of the ideas involved was rather more sophisticated and desirable. The picture ëit just happens by itselfí was chosen as a match for three situations. For all three, but also for another two, it was an appropriate match. These three included the physical changes ëice forming on a pondí and ëa hot bath cools downí; unlike the first interview, no pupil seemed to hesitate this time about their matching. Moreover, the explanation of why ëacid rain eroding a stone statueí ëjust happens by itselfí interestingly seemed to suggest that spontaneity is not related to the absence of causal agents in general (as was suggested in the first interview), but more particularly to the absence of *external* agents acting on a change:

> *Because acid from the rain is just going into the statue. Nothing is making it go or nothing is forcing it. Thereís not electrical or anything forcing the acid rain to, you know, touch the stone statue. Itís just happening, and it happens by itself. The acid rain touches the stone statue and the chemicals in the acid rain are making the stone statue dissolve.*

Chemicals were seen to act as *internal* agents of the change and thus as not affecting its spontaneity. This idea could be seen as a potential precursor of the more explicit understanding that inward flows of energy and/or matter accompany non-spontaneous changes. Indeed, the first signs of this growing understanding coupled with the corresponding awareness that outward flows of energy ëjust happen by themselvesí were present in some other explanations, even in not always the most desirable wording. For example, a pupil justified matching the situation ërunning and using up foodí to the picture ëit ëjustí happens by itselfí because *"it donít need no help taking energy out"* and another one agreed because *"every single thing that you do [...] youíre using up energy, so the energy is just coming out naturally"* . The latter interpretation of the expression ëit ëjustí happens by itselfí as ëit happens naturallyí seems very acceptable, but (as the project found when using the expression ëit happens naturallyí) has a possible pitfall, as the two expressions can be and often are understood differently. For example, in the present analysis the same interpretation led a pupil to reason that ëa plant growingí ëëjustí happens by itselfí, i.e. is a spontaneous change.

Returning to the previous point, ëwood burningí was also said to ëhappen by itselfí because *"[...] the wood is already done - you wonít need the energy to go in in the first place"* . Both changes however, ërunning and using up foodí and ëwood burningí, originally intended to be thought of as spontaneous, were eventually left matched to the picture ëit needs something to make it happení. For the situation ërunning and using up foodí the decision was taken after an extended and heated discussion. The arguments against it being accepted as ëhappening by itselfí were that energy has to come in before it can be released ñ *"you need the food for that person to run"* - and that an activity is needed to trigger the release of energy ñ *"you arenít exactly just going to sit there and wait for it to come out, you have to at least do some walking around or jogging"* . For the situation ëwood burningí the discussion was also animated and very interesting.

In it the rationale employed in the first interview that no change can happen by itself as it must be always preceded by actions which set up the necessary conditions for it to happen, was seriously challenged.

If people are going to keep on going back saying that this happened and that happened, you might never get to where it happens, because you consider: Is the oxygen and the wood that has to burn [there], before this is happening?

The discussion continued on whether lighting up the fire is part of the change ëwood burningí or not. Defining the system as well as what constitutes the ëbeforeí and ëafterí instances of the change under consideration is essential, though not at all trivial, for thermodynamic accounts. The children in the following extract are actively involved in both.

P: *You need something to make it burn.*
P: *You need wood to make a fire, you need a fire...*

P: *You need to strike a match. A human hand to make the match strike.*

P: *Even though fire doesnít come out like that. You need like say at least a magnifying glass and the sun.*

[...]

P: *[...] this is wood burning not the fire getting lit up or whatever happening, this is wood burning. This is what is happening right now, not what happened before. [...] When wood is burning, itís burning OK, itís burning by itself, you donít need something to make it happen, to keep on burning more.*

P: *But you do though because if you never had something underneath the fire then it wouldnít, the fire wouldnít have started anyway.*

P: *But the wood is now burning, so nothing needs to happen to make it burn more. OK, I know you have to light a fire to make the wood burn but now that itís already burning you donít need anything else to make it burn more. Itís burning and itís burning and itís just happening by itself and the energy is going out and the thing is getting cold.*

P: *Miss this thing isnít very clear, so itís very confusing about this thing, wood burning. I mean they might as well put it out as ëwood is burningí, or ëhow does wood burní, because Iím getting confused now.*

On the whole the picture ëit needs something to make it happení was chosen as a match by one or more pupils for six out of the eight situations; it was finally kept for five of them, for three - ëa plant growingí, ëcharging a car batteryí and ëpulling a catapult to get ready to fire a stoneí - appropriately. In none of these cases was it explicitly acknowledged that another spontaneous change needs to happen to drive these changes.

As for the application of the phrase ëit is easy to reverse the changeí the focus seemed to be more on identifying the ëreverse changeí than on thinking about whether this happens more easily or not. Moreover, this identification did not seem always to respect the necessity for the identity of the participants to be conserved in any ëreverse processí.

Similar observations were made from the interviews performance of the pupils of the second group. On the whole the pupils did not seem to have difficulties correctly recognising the reverse processes of physical changes right from the first interview. In the case of the change ëcleaning a paintbrush in waterí (which appeared in the second interview) they also described the mechanism - filtering - and acknowledged that *"itís going to be hard, unless you filter it a thousand times"* . For more complicated changes, like ëextracting copper by electrolysing copper sulphate solutioní or ëcharging a car batteryí they either attempted but found very difficult to say what the reverse process consists of - *"you have to add something in it to make that copper solution"* - , or did not attempt it at all by suggesting the repetition of the change instead of the reversal of it - *"say it [the car battery] runs out, you can charge it again"* . The latter happened only in the last interview, but for all the changes discussed (even for the ëeasierí one ëa hot bath cools downí), which rather suggests an incorrect reading of the phrase ëit is easy to reverse the changeí, rather than an incorrect use of it.

Conclusion

In the above accounts we follow the progress of eight pupils in the course of eight months. In particular, we see how these pupils responded to the novelties introduced by the curriculum materials which were developed by the *Energy and Change* project and were used in their science lessons. One of the key issues the study addresses is how well children manage comparisons of different physical and chemical changes. The features of the changes that children pay attention to in seeing similarities are identified and are discussed in terms of the childrenís ability to generalise in changing contexts. The role of the use of abstract pictures to that end is examined and assessed.

More specifically, the analysis of the pupilsí interviews tells us how well the children managed to use the terms and ideas introduced by the project to describe what is happening in a variety of familiar and less familiar changes. Although there were more than a few cases where the pupils seemed not to be able to make full use of the projectís ideas, overall the pupils worked well with the activities; they made sense of the abstract pictures and managed to reason successfully in matter and energy terms about a variety of physical and chemical processes. Moreover, based on the rest of the data collected (for example, lesson observations, pupilsí written work) it is evident that the successes and difficulties demonstrated by these pupils in the above interviews were more or less typical of the rest of the pupils in the class.

The analysis also examines the sort of comparisons children did, at first spontaneously and then aided by the abstract pictures. t was the case that in the first interview the pupils focused more on the superficial similarities of the changes; by the fourth interview they more readily reflected on what was happening in the changes and identified similarities between the processes involved. Matching the changes to the abstract pictures seemed to further enhance this reflection on the nature and causes of change and prompted interesting discussions among the pupils at a fairly high level of generalisation.

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