

**LEARNING ABOUT ENERGY AND
PROCESSES OF CHANGE:
AN INVESTIGATION OF NOVEL ASPECTS
OF A CURRICULUM INTERVENTION**

by

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ABSTRACT

A fundamental aspect of scientific thinking is to account for why things happen, and this can be addressed by using ideas from the Second Law of Thermodynamics. These ideas are however traditionally not attended to in lower secondary school science. The present research is an evaluative study of the novel curriculum approach developed by the 'Energy and Change' project. This novel approach introduces 'Second Law thinking' in ways accessible to pupils aged 11 upwards. To accomplish this, the project developed an abstract 'picture language', through which a coherent and systematic account of the fundamental nature of all changes is told.

The research was carried out in two phases. The first phase had an exploratory character and was concerned with the development of the research tools. In the second phase, the study examined the user-friendliness of the innovative aspects of the approach for pupils and teachers; the pupils' learning progress from using the innovation; and the merit of the materials for teaching, as well as for teachers' personal development. The focus was on two classes of pupils (aged 11-12 and 12-13) over a period of eight months using the approach to study a variety of science topics. An intensive investigation of the influence of the new approach on these pupils' understanding of the nature and causes of change was undertaken, based on records of their written work, observational records of lessons and small group task-based interviews. Moreover, the views of science teachers about the approach were elicited in questionnaires and interviews.

The research concludes that the innovative aspects of the new approach were broadly accepted by both the pupils and the teachers who took part in the study. Moreover, it reveals and discusses the difficulties and challenges the pupils met when using the intended thermodynamic ideas in their explanations of change.

**To my mother Rosy,
my stepfather Nicos
and the memory of
my father Stelios**

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CHAPTER 1

Introduction

1.1 The thesis, the project and I

The project and I 'met' in September 1992. I had just completed my studies for a Master's degree in science education. As part of the degree I had written a dissertation on 'What is involved in understanding energy?' (Stylianidou, 1992). This consisted of an extended and structured review of the then existing literature on the teaching and learning of energy. It ended with the comment:

"[...] All these are questions waiting to be answered. Moreover, there are almost no empirical studies to give information concerning the learning of the Second Law. From its teaching, new alternative frameworks may arise, that we cannot conceive of. It is an area almost virgin for educational research, and indeed very challenging. It could be the only way ahead for an effective teaching of energy."
(p109)

The project, on the other hand, had just been given the 'go ahead' by the Nuffield Foundation to develop a novel approach to teaching about energy and processes of change, which would introduce Second Law ideas in ways accessible to pupils in the lower secondary school (i.e. 11-16 years old). The attraction was instant and mutual. Out of it, in January 1993 the thesis was born.

The thesis today - this thesis - is an evaluative study of the innovative aspects of the curriculum approach developed by the 'Energy and Change' project.

Of course reality is always more complicated and perhaps less romantic, this is why some more things need to be said about the interest and nature of the research reported in this thesis.

Why was this study worth doing?

The 'Energy and Change' project developed a teaching approach (and corresponding curriculum materials), which has no precedent both in terms of its objectives, and in terms of the means it uses in order to meet these objectives. To clarify this further, although there exist a small number of curriculum approaches that introduce Second Law ideas to pupils at the lower secondary school (i.e. aged 11-16) (see, for example, Arnold and Millar, 1996b; Ben-Zvi, 1999; Herrmann, 1992, 1997; Linn and Songer, 1991), with the exception of the Israeli module on 'Energy and the Human Being' (Ben-Zvi, 1999), (which is aimed at non-science oriented students aged 15+), the rest

deal only with thermal phenomena and the heat-flow model of thermodynamics. The ‘Energy and Change’ approach addresses the teaching of a variety of physical, chemical and biological changes in a consistent and unifying way, and in this sense it is unique. Moreover, the reason why it is unique is that its aim is considered by many educationalists very desirable (see, for example, Atkins, 1983; Black and Solomon, 1983; Duit, 1983; Ogborn, 1976b, 1990; Sexl, 1983; Solomon, 1982), but at the same time non-trivial. Second Law ideas have a reputation of being obscure and difficult to understand; some researchers have even regarded them as totally inaccessible for pupils of this age group (see, for example, Warren, 1994). The interest, therefore, of the implementation and evaluation of the ‘Energy and Change’ approach follows.

More particularly, this study investigates the accessibility and usefulness of the novel teaching approach and curriculum materials to pupils and teachers. The research questions are concerned with the user-friendliness of the innovative aspects of the approach for pupils and teachers; the pupils’ learning progress from using the innovation; the merit of the materials for teaching; and their merit for teachers’ personal development.

What was the nature of this study?

In common with all research, the nature of this thesis was shaped and determined by a number of factors. Most importantly it was carried out in parallel with the development of the teaching approach it aimed to evaluate and was supervised by the authors of this approach (Jon Ogborn and Richard Boohan). As a consequence, the relationship between this work and the teaching approach was close and interactive, the approach informed the research and the research informed the approach.

This feature of the work also meant that I had a close relationship with the authors of the curriculum materials, I had frequent discussions with them about their work as well as this thesis. The fact that I worked so closely^{with} (and was supervised by) the authors of the curriculum materials does not make this work an ‘inside job’ since both the supervisors were at constant pains to stress that this work was *my* evaluation of the approach they were developing. However, this relationship, combined with my initial belief in the goals of the project may have made me prone to optimism.

What kind of evaluation is it?

It includes elements of both formative and summative evaluation. Formative, as already explained, in that the development of the curriculum materials, as this happened, informed the design and implementation of the research, and the research, by providing constant feedback about the use of the curriculum materials in the classroom, informed their development. Summative in a small sense, the focus rather

being on understanding and describing what ‘works’ and what ‘does not work’ – establishing on the one hand whether the teaching approach met its objectives, but most importantly saying why or why not. In other words, I see the thesis’s aim mainly as one of identifying and describing the issues from the points of view of the project, the pupils and the teachers. In this sense the evaluation design is in broad agreement with the ‘illuminative’ perspective (Parlett and Hamilton, 1976).

It is a small-scale evaluation, working in one school with two classes (one Year 7 and one Year 8) for the most part of a school year. I had no sole control of the choice of school, or of the planning of the teaching intervention. These were arranged by the project in consultation with me. In this sense it is an opportunistic research. However, in the school in which the teaching intervention took place the majority of the children come from ethnic minority groups, speak a number of different Asian languages at home and many have difficulties of expression in basic English. Thus, the context of the evaluation was in no sense privileged.

The research treats all the children who took part in the intervention as the “experimental” group, using knowledge from literature results concerning more conventional approaches as the “control”. It combines case studies of pupils and teachers with systematic (though small scale) analysis of patterns and frequencies of responses and trends in time.

Finally, the following quotation taken from a similar kind of evaluation study (Arnold and Millar, 1996b), could not sum up better the case.

“This approach to curriculum research addresses the frequent call (see, e.g., Linn, 1987) for closer links between educational research and practice. As a result, however, it is open to the standard criticism of classroom-based research, that extraneous variables which cannot easily be controlled may have a significant influence on the outcomes. It is also constrained by the opportunities available for this sort of curriculum intervention.” (p256)

The hope, however, is that this research has managed to make the best of both these opportunities and constraints.

1.2 The thesis in outline

As already mentioned, the research questions of this study are concerned with the accessibility and usefulness of the novel approach. In order to understand fully these questions it is first necessary to explain both the innovative aspects of this approach and the context within which it is set. These are therefore discussed in chapters 2 and 3.

Chapter 2 presents the project ‘Energy and Change’ and its suggested teaching approach. It refers to the scientific ideas behind the approach and the design of the teaching materials, and identifies the key issues which arise from them in relation to the research questions of this study.

Chapter 3 aims to give an overview of relevant published research and, where appropriate, to explicate the position of the novel teaching approach with respect to the issues identified in this literature. The studies discussed refer to pupils’ conceptions about different kinds of changes to matter and to energy. The topics are selected to be relevant to the ideas explored in the materials used in the teaching intervention.

Chapter 4 sets out the initial exploratory studies used in the development of the new approach and explains how these studies led to the development of the structure and method of the interview tool to be used in the main study.

Following this scene-setting, chapter 5 discusses the design of the main study. It sets out the research questions and includes a description of the methods used for the collection of the data and the rationale for the choice of them. It also explains the process which was followed in the analysis of the data and provides a map to show the sources of data used in and the research questions addressed by each of the outputs of the analysis.

Chapters 6 and 7 discuss the analyses of the data collected for the Year 7 class. Chapter 6 is concerned with the pupils ‘in the classroom’ and contains details of the pupils’ experiences in the intervention lessons together with case studies of selected pupils and their teachers. Chapter 7 discusses from different perspectives the analysis of the interviews carried out with groups of pupils. Due to the extent of the data, chapter 7 includes only examples of this analysis for one group of pupils. It should be read in conjunction with appendices 7.5-7.9, which contain further examples of the analysis. The chapter concludes with a synthesis of all the Year 7 findings.

Chapters 8 and 9 discuss the analyses of the data collected for the Year 8 class, structured in a way similar to chapters 6 and 7. Moreover, similar to chapter 7 and for the equivalent reasons, chapter 9 should be read in conjunction with appendices 9.5-9.7. Chapter 9 concludes with a synthesis of all the Year 8 findings.

Chapter 10 contains the analysis of science teachers’ reactions to the innovation based on questionnaires to science teachers trained in the new approach, as well as on extended interviews with the science teachers of the school used for the intervention.

Finally, chapter 11 summarises the main results in connection with the research questions and discusses the strengths and limitations of the present evaluation.

CHAPTER 2

Project 'Energy and Change'

2.1 Introduction

In this chapter I will present the project 'Energy and Change' and its suggested teaching approach. I will refer to the scientific ideas behind it and the design of the teaching materials.

The project 'Energy and Change' was run by Richard Boohan and Jon Ogborn from September 1992 to July 1995 at the Institute of Education, University of London, and was funded by the Nuffield Foundation. It aimed to provide a novel approach to teaching about processes of change, which introduces thermodynamic ideas in ways accessible to pupils at the lower secondary school (i.e. aged 11-16 years).

The following account is intended as a brief overview of this novel approach as well as of the teaching materials developed by the project; it does not contain an elaborate description of the materials or attempts to justify in great detail the ideas involved. The account draws on information found in the project's main publications (Boohan 1996a; Boohan and Ogborn 1996a), particularly in the booklet 'Introducing a new approach'. It also draws on other material published by the project's authors and myself (Boohan, 1996b, 1996c, in press; Boohan and Ogborn, 1996b, 1997; Ogborn, 1994; Stylianidou, 1993, 1997a, 1997b; Stylianidou and Boohan, 1998, 1999), about the new approach and its use by children.

2.2 Starting point for the project

The 'Energy and Change' project was developed to address the need identified by curriculum developers for pupils to make sense of a variety of processes of change and to produce explanations about what causes these changes to occur. Since the direction of change is the concern of the Second Law of Thermodynamics, this need was further interpreted as a need for pupils to understand and use Second Law ideas. However, these ideas have a reputation for being obscure and difficult to understand, and thus have traditionally received only a little attention at the lower secondary school level. Instead, the concept of 'energy' has been recruited as a cause of change. This is not only inappropriate scientifically, but has also created a great deal of confusion about teaching energy (see Stylianidou, 1992, pp68-70). Having identified this situation, the project's authors wanted to rectify it.

The project, therefore, developed an approach, and produced curriculum materials, for talking about energy and processes of change, which take account of 'Second Law' ideas, and are addressed to pupils aged 11 years and upwards. In developing this approach, an important consideration was that the new way of talking about change was built on common-sense notions about why things change, so that it would be potentially intelligible to *all* pupils. Equally important for the authors was that the new approach was scientifically consistent, so that the pupils who later specialise in science can build on the ideas in a natural way, and finally, that it proved useful to teachers.

2.3 Rationale for using 'differences'

The fundamental idea, on which the new approach was based, was that change is understandable as being caused by 'differences' (Ogborn, 1990), such as those between hot and cold, concentrated and dilute, pure and impure, bunched together and spread out. The idea of 'differences' relates to the scientific concept of 'negative entropy', and the key principle is that *differences drive change*, and in doing so, *tend to decrease* (which is a way to say that entropy tends to increase), and eventually to disappear. Another way of looking at this is to say that the informal notion of 'differences' corresponds to the scientific concept of 'free energy' – both tend to be used up during a spontaneous change. Differences can also be created, but to do so a larger difference needs to be used up. It may be also necessary to use up a difference to keep another one in being (e.g. steady state systems). Finally, a difference can be preserved and thus a change prevented by either walling off the difference (that is, blocking the path of the change), or freezing the difference (that is, slowing down the change).

2.3.1 Scientific rationale

In this section, I will explain briefly how the story of 'differences' is related to the more usual account in terms of entropy and/or free energy. None of this rationale is, of course, part of anything presented to pupils in the early years of secondary education.

Perfume spreads in a room because of a concentration difference, and in doing so this difference decreases and eventually disappears - the perfume becomes evenly spread out. Hot chocolate cools down because of a temperature difference; it eventually becomes the same temperature as the room. A decreasing difference corresponds to an increase in entropy. Differences tend to decrease because the total entropy always increases in any irreversible change. Entropy (S) is a measure of the number of

microstates consistent with a given macroscopic state (W) (or $S = k \ln W$, where k is the Boltzmann constant). So, returning to the previous example, perfume diffuses in a room because there are more microstates consistent with the state in which the perfume is spread throughout the room, than when it is concentrated in one region. For a similar reason, entropy increases when hot chocolate cools down.

Differently said, entropy measures how smoothed out a system composed of many particles is, including the arrangement and distribution of energy amongst the particles. If the matter and energy in a system are unevenly spread out, the system has a smaller entropy compared to a more evenly spread out state. Therefore, changes in which energy and/or matter spread out are spontaneous processes.

Changes involve energy going from one thing (or place) to another, and/or matter going from one place to another or changing from one kind to another. According to the project all these changes can be seen as driven by two main kinds of differences: in temperature and in chemical potential.

2.3.1.1 Changes driven by temperature differences

These changes involve energy flowing from one thing (or place) to another, and more specifically from hotter things (or places) to cooler ones. They are driven by temperature differences. In the project, temperature is portrayed as a measure of the concentration of energy; since the energy in each degree of freedom per particle is of the order of $1/2 (kT)$, hot things have particles with a lot of energy each, and cold things have particles with little energy each. Therefore, saying that a change is driven by temperature differences is like saying that spontaneously ‘energy becomes less concentrated’, or that ‘energy spreads out’.

In entropy language the same idea can be explained as follows: Since the entropy change of an object at temperature T is $\Delta S = (\pm) \varepsilon / T$, where ε is the energy gained, or lost respectively, the total entropy of the two objects in contact, or of the system and its surroundings, increases when a given energy ε leaves the hotter object/place and enters the colder object/place.

2.3.1.2 Changes driven by differences in chemical potential

These other changes involve particles moving from place to place or changing from one kind to another. They are driven by differences in chemical potential, which in the process tend to decrease. In entropy language this idea can be explained as follows: since the total entropy change of moving a particle at constant pressure and at temperature T is $\Delta S_{\text{total}} = - \Delta \mu / T$, where $\Delta \mu$ is the change in chemical potential, one can see that the change in entropy and the change in chemical potential are

proportional, but opposite in sign. Therefore, the total entropy of two coupled systems increases when particles leave regions of high chemical potential and enter regions of lower chemical potential.

One of the simplest cases of chemical potential difference is a pressure difference. Material at high pressure in a fire extinguisher squirts out if the valve is opened; the particles tend to travel, on average, down the pressure gradient. Equally simple is a concentration difference. Water-colour paint in water spreads out until the colour is uniform; the particles tend to travel, on average, down the concentration gradient.

Particles are also moved from place to place by forces caused by potential fields, such as the gravitational potential field, or the electrical potential field. Matter tends to travel, on average, down a potential energy gradient. In the gravity field of the Earth, for example, the potential energy gets less as one gets closer to the Earth, and so matter is pulled down this gradient. These differences in potential energy (gravitational or electrical) contribute to the overall chemical potential difference.

Other contributions to the overall chemical potential difference come from changing the numbers of particles of different species. This happens in chemical reactions. Generally, removing particles increases the chemical potential difference, while adding them decreases it.

Summing up, in the project's approach, all these changes

"...can be thought of as caused by differences in chemical potential, with pressure differences, concentration differences, gravitational, electrical and other potential energy differences, being special cases of or contributions to the chemical potential." (Ogborn, 1994, p7)

2.3.1.3 Reversible changes

Reversible changes such as the movement of the planets, or the propagation of waves, are thought of as 'no changes' thermodynamically and in the 'differences' approach. This is because they involve processes which can be reversed in time, following the same path going backwards as the path going forwards, without using up any 'difference'.

2.3.2 Pedagogic and curriculum considerations

The idea of relating changes to the destruction (and creation) of differences, apart from being scientifically justified, seemed also to have several other advantages. The project's authors identify these as:

"Human beings notice differences - light and dark, loud or quiet - rather readily. That the cause of a change gets used up in the process

seems a natural thought, and one usefully able to be related later to the idea of using up fuels. It seemed easy to understand that differences vanish all by themselves just because of the random behaviour of molecules ‘going nowhere in particular’. And it meant that we could try to bring potential energy differences, which were there in the curriculum in any case, into the same scheme.” (Boohan and Ogborn, 1996b, p17)

2.4 The project’s view of ‘energy’

The new approach addresses much more than the teaching of ‘energy’; it forms a consistent story about processes of changes, which can be used in many areas of the science curriculum across the whole age range. However, it is of special interest to mention how it deals with the concept of ‘energy’, not least because the project developed partly out of the dissatisfaction its authors felt with the current state of teaching of energy (Boohan and Ogborn, 1996b).

As already stated, in the project’s approach energy does not drive change, ‘differences’ do, including differences in the concentration of energy (i.e. temperature). As a result of these differences energy is transferred from where it is concentrated to where it is less concentrated. Such an account stresses the importance of thinking about energy as *staying the same kind of thing* as it goes / flows / is passed on from object (or place) to object (or place). It also complies with the requirement of the National Curriculum (DFE/WO, 1991, 1995; DfEE/QCA, 1999) not to refer to ‘forms of energy’ in the teaching of energy, but instead to focus on the processes of ‘energy transfer’.

Energy may not drive change, but it sets the limits for the possibility of change. This quantitative aspect of energy is not ignored by the project; it is addressed in materials to be used with the older pupils, in the form of comparisons of the amounts of energy transferred from and to various kinds of systems.

According to the project, this way of approaching the teaching of energy in the classroom has two important advantages. First, it is scientifically correct and consistent. Second, it makes the discussion in science classrooms about important matters like food, fuels, and life, more sensible and intelligible, given that it introduces the idea of ‘the something that is used up’ (i.e. ‘differences’), which is more intuitive for pupils, before the more difficult one of ‘the something that is conserved’ (i.e. ‘energy’).

2.5 Telling the story in words and in pictures

Part of the attraction of using the idea of ‘differences’, as already mentioned, was that it can be used to make sense of a wide range of phenomena, from simple

temperature changes to complex biological processes. This account however also required pupils to see very different-seeming things – such as a heated room and a person’s warm body – as essentially similar. To help make these similarities clearer, and more generally to help pupils reason about change in terms of what is happening to the particles and the associated energy, the project developed a range of *abstract pictures* together with a consistent way of talking about them. These pictures show only the essence of what is happening in a change – for example, a difference in concentration vanishing, or energy flowing into or out of part of a system -, and are intended to be a tool to help pupils represent and discuss the story about differences and change in a wide variety of processes. The project’s authors saw the use of the abstract pictures in the classroom as follows:

“We very much hope that these pictures will not settle into a new orthodoxy – yet one more thing to learn and repeat back. We see their value as provoking useful discussion with and between pupils about what is or may be going on in a change, whether it be perspiring or building up a storm. No doubt teachers can improve on them for their own purposes, preferably in discussion with pupils about what one might want to represent. What they must do is to represent the essential mechanics of part of a physical process, including where energy is going, and must indicate which way round the event is happening together with whether it is spontaneous or not.” (Boohan and Ogborn, 1996b, p19)

Though the use of visual communication is very common in science education (Barlex and Carré, 1985), mostly it is concerned with the representation of spatial and sequential relationships, rather than of conceptual ideas, though there have been some uses of abstract pictures to explore pupils’ conceptual understanding (for example, Novick and Nussbaum, 1981).

In the following subsections I will give an overview of the abstract picture language developed by the project and say a few words about how this language represents the story of ‘differences’.

2.5.1 Fundamental kinds of changes

Though there is a wide range of different pictures which are able to represent specific kinds of change, there are a relatively few fundamental kinds of changes.

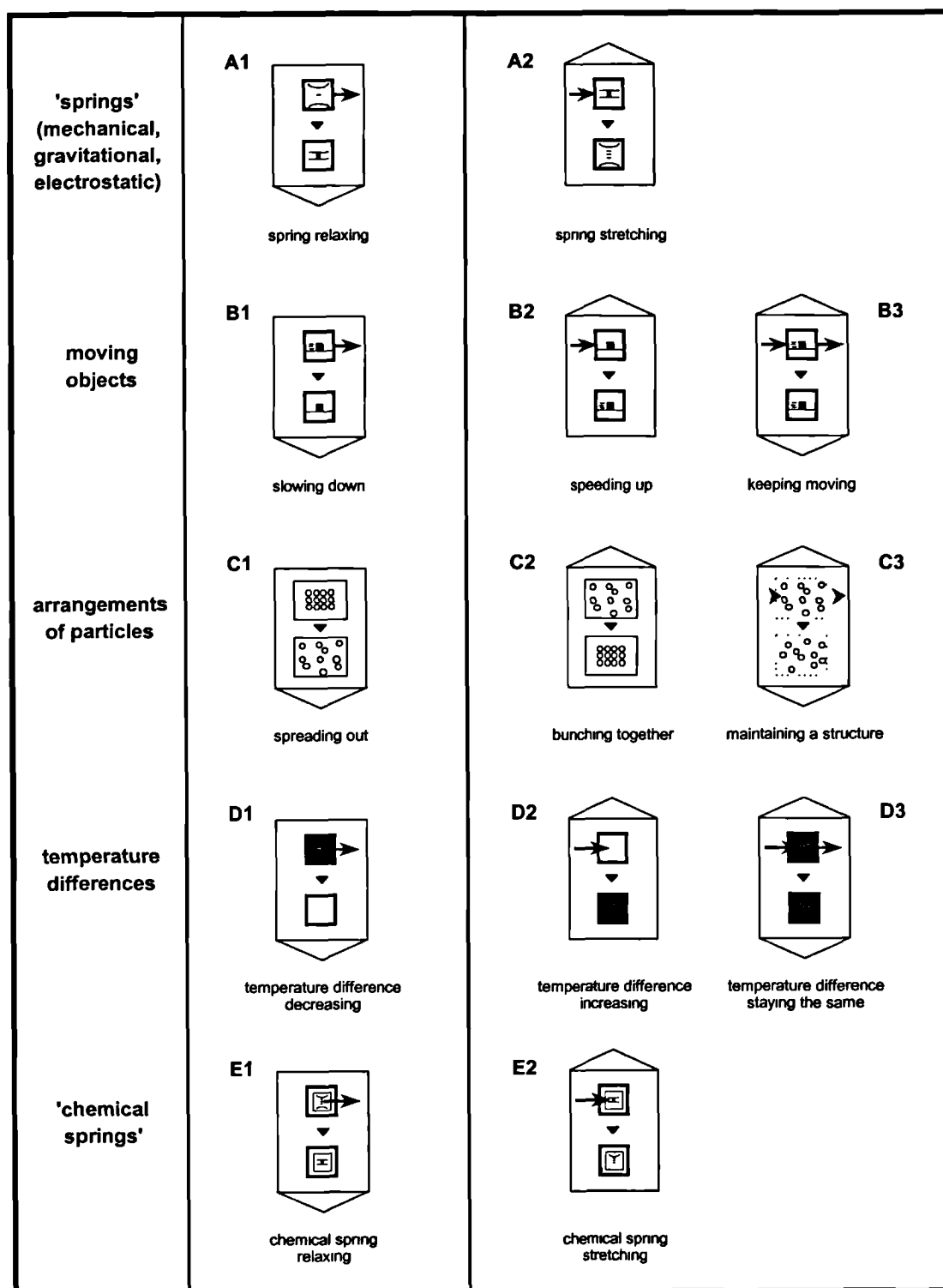


Figure 2.1 Fundamental kinds of changes

The project identified five fundamental kinds of changes: four of them involve an energy transfer, whereas one is concerned solely with matter changes. Figure 2.1 shows the pictures that the project developed to represent these fundamental kinds of changes. Combinations of these pictures can be used to represent any kind of thermodynamic change.

Each box, shows a 'before' and an 'after' state of affairs, with the small black triangle indicating the direction of time (i.e. from top to bottom). The large arrow at the bottom and/or top of each box represents the direction of spontaneous change. All the changes on the left are therefore spontaneous changes – the triangular arrow is pointing down at the bottom of each box. To talk about such changes, the project uses expressions such as 'it just happens by itself', or 'it happens more easily forwards', or 'this is a downhill change'. In the same way, all the changes on the right of Figure 2.1 do not 'just happen', they need to be driven by changes which 'just happen'. Figures 2.1.B3, 2.1.C3 and 2.1.D3 represent steady state systems, and thus have each both a 'downhill' *and* an 'uphill' arrow.

Figure 2.1.A1 represents any change in which energy, stored up in a potential energy difference, escapes and spreads out. This could be a mechanical spring being released, or could be any gravitational or electrostatic attraction. Conversely, Figure 2.1.A2 represents any change in which energy is stored as a potential energy difference, an example being the pumping of water uphill to a reservoir.

Figure 2.1.B1 represents any change in which energy spreads out as a result of a moving object slowing down. Objects in the real world do not start to move 'just by themselves' (Figure 2.1.B2); they do not even continue to move at constant speeds 'just by themselves', they are being kept in a 'steady state' by a constant flow of energy (Figure 2.1.B3). Of course in a world without friction there is no need for an energy flow to keep an object moving at the same velocity, and this change would be represented in a picture omitting the 'up' and 'down' arrows indicating spontaneous change, but with the object continuing to move.

Figure 2.1.C1 represents any change in which matter becomes more disordered, including for example changes in which particles are 'spreading out', 'mixing' and so on. Conversely, Figure 2.1.C2 depicts any change in which matter becomes less ordered, and Figure 2.1.C3 any change in which a particular structure is maintained by a continuous flow of matter. A pressure difference between a leaky air container and the outside, for example, could be maintained by a continuous flow of air into the container, to balance that escaping.

Figure 2.1.D1 represents any change in which energy flows down a temperature gradient. Temperature is depicted by the shading – the darker the shading, the higher the temperature – and the arrows out or in (see Figure 2.1.D2) depict flows of energy. Figure 2.1.D3 *"shows a steady state system maintained at a constant temperature, away from equilibrium, with a continuous flow of energy – such a system, like other non-spontaneous changes, needs to be driven by a change which 'just happens'"* (Boohan and Ogborn, 1996a – 'Introducing a new approach', p20).

Finally, Figures 2.1.E1 and 2.1.E2 represent changes in which energy is released and stored respectively as a result of chemical bonds being formed and broken. To show these kinds of changes, the project uses the metaphor of the ‘chemical spring’. With this metaphor, the combustion of a fuel, for example, can be accounted for as follows: as fuel and oxygen combine, and bonds are broken and then formed (‘joining’ is the term the project uses with the pupils), the stretched ‘fuel-oxygen spring’ collapses and energy already stored in this ‘chemical spring’ is ‘released’ and gets spread out into the surroundings (Figure 2.1.E1). In an equivalent way, chemical bonds being broken, e.g. when particles are ‘splitting’, are represented as the ‘pulling apart’ of a ‘chemical spring’ (Figure 2.1.E2). The merit of these pictures, according to the project, lies in the fact that they “*emphasise that in ‘joining’ energy spreads out, while in ‘splitting’ energy is stored*” (Boohan and Ogborn, 1996a – ‘Introducing a new approach’, p17). This is important because among children there is a widely held belief that energy is stored in bonds and released when the bonds are broken (see relevant discussion in subsection 3.2.3.5).

A synoptic way of accounting for all fundamental abstract pictures which involve an energy transfer (i.e. Figures 2.1.A1, 2.1.B1, 2.1.D1, 2.1.E1 and their opposites) is to say that each represents a potential or kinetic energy change happening either macroscopically or microscopically. Table 2.1 shows how the four kinds of fundamental energy changes described above can be explained under this perspective.

	Macroscopic	Microscopic
Potential energy changes	‘springs’ (mechanical, gravitational)	‘chemical springs’
Kinetic energy changes	moving objects	temperature differences

Table 2.1 Fundamental kinds of energy changes

While the limited set of pictures shown in Figure 2.1 depicts the fundamental kinds of changes, further sets of pictures related to each fundamental picture allow finer discriminations to be made. For example, when representing an energy transfer due to a temperature difference, it may be useful to refer to more specific features of the change, such as whether there is an energy exchange with the surroundings, or whether the system is at a higher or lower temperature than the surroundings. Or, when accounting for changes in which matter becomes more disordered, it may be useful to refer to whether particles are ‘spreading out’, ‘mixing’, or ‘splitting’, or whether it is the case that a large complex molecule is breaking down. Such more

specific pictures have been developed by the project and are used in the teaching materials.

2.5.2 Coupled changes

“Changes may be coupled together so that a change which ‘just happens’ drives a change which does not.” (Boohan and Ogborn, 1996a – ‘Introducing a new approach’, p8). The limited set of pictures discussed above are particularly useful when considering how changes may be coupled. Figure 2.2 shows two examples of such coupled changes in which a spontaneous change is driving a non-spontaneous one (Stylianidou and Boohan, 1998).

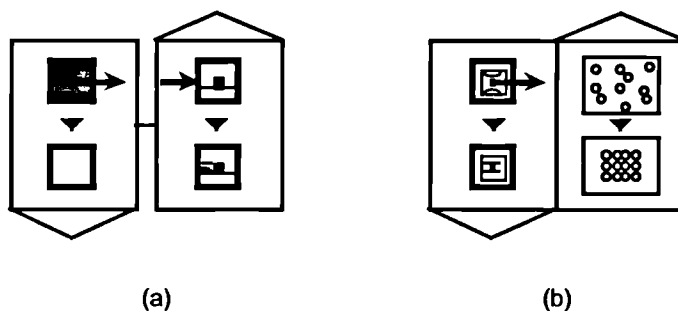


Figure 2.2 Coupled changes

In Figure 2.2(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 be for example a steam engine. In Figure 2.2(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. A distinction is made in these pictures between changes in which one system is coupled to and drives another, as in Figure 2.2(a), and changes which take place within a single system, as in Figure 2.2(b).

The above ideas and pictures are of course not intended to be introduced to pupils all at once, or right at the start of the teaching approach; they are meant to build over time into a consistent story about change. They are also meant to lay the foundation for introducing more difficult concepts, such as entropy, free energy and chemical potential, in post-16 education. Moreover, “[...] *they can complement an approach to matter and energy spreading based on probabilistic behaviour* (Atkins 1984), [and] *...can help to illustrate quantitative work*” (Boohan, 1996b, p94).

2.6 Work with pupils

The project produced over eighty activities for pupils (Boohan, 1996a). These activities are not a course in themselves, but are designed to be used alongside

schools’ existing resources. Moreover, they all relate to topics which are already covered in the existing curriculum; *“they do encourage, however, different ideas to be emphasised in such topics, such as identifying differences in concentration or temperature”* (Boohan and Ogborn, 1996a – ‘Activities for the classroom’, p1). The project ideally intended that the activities be incorporated in the schools’ schemes of work, so that the new ideas would be developed progressively and in a consistent way throughout the whole period of compulsory secondary education (Key Stages 3 and 4). However, anticipating that this might not be feasible or desirable for many teachers, its authors designed the activities in a way that it is possible for a teacher to pick out one or more of them and try it/them out with pupils on its/their own merits without committing him/herself to the whole approach. Therefore, a number of the activities do not require previous experience with other activities in order for them to be used successfully.

The activities are grouped in ten thematic units. Each unit contains about eight pupil activities with accompanying teaching notes. Table 2.2 shows the themes of the units and gives a brief description of their contents (Boohan and Ogborn, 1996a – ‘Activities for the classroom’, p57; Boohan, 1996a).

Thematic Units		Content
A	Mixing and ‘unmixing’	The theme is concerned with simple changes to substances, e.g. dissolving and mixing, purifying and separating mixtures. It contains many familiar examples of these changes from everyday life. Pupils are encouraged to identify the changes which happen more easily in one direction, and to account for them in terms of what is happening to the substances involved – are they ‘spreading out’ or ‘bunching together’?
B	Hot and cold	The activities in this theme are concerned with looking at temperature differences, at what temperature differences can do and how they can arise. Pupils are encouraged to pay attention to temperature differences, to think about their relative sizes, and to notice that they tend to level out or become equal at the end of a change. The concept of energy is not introduced in these activities.

C	Solids, liquids, gases	This theme contains further activities on changes to substances, with an emphasis on changes involving gases (e.g. smells and air pollution) and on changes of state. Pupils are encouraged once more to pay attention to what is happening to the concentration of the substances involved. They are moreover prompted to think about the nature of these substances, and the possible changes to it. Finally, they are asked to reason that changes of state are caused by temperature differences.
D	Life	The theme is concerned with the concentrations of substances in living things and in the environment, and with how these concentrations are maintained. Pupils are encouraged to account for changes in the amounts of substances in organisms and the environment in terms of processes of 'spreading out' and 'bunching together'.
E	Energy from hot to cold	This theme is concerned with energy transfers due to temperature differences. The activities contain many familiar examples of such energy transfers from everyday life (e.g. energy transfers in the kitchen). Pupils are encouraged to identify energy flows from hot to cold, and to reason that energy 'spreads out' from places where it is 'concentrated'.
F	Particles and change	In this theme the focus is on using particle pictures to represent different kinds of physical and chemical changes (e.g. melting, combustion, corrosion, metal extraction). Pupils are encouraged to pay attention to how particles may become more spread out or mixed together, as well as to whether new substances are formed in these changes.
G	Up and down in complexity	This theme focuses on the idea that in a chemical reaction, particles form new particles by splitting, joining, re-combining. It is also concerned with establishing a scale of complexity of molecules and identifying changes which go up or down the scale of complexity, e.g. fermentation, photosynthesis, decay, polymerisation. Pupils are encouraged to reason that spontaneous changes go in the direction in which complexity disappears – i.e. large particles break down to form smaller ones.

H	Fuels and food	This theme is concerned with the energy transfers present in the making and using up of fuels and food. Pupils are encouraged to reason that storing energy in fuel-oxygen systems is similar to stretching a spring. The activities also make the essential point that a change which 'just happens' (e.g. a fuel burning) can drive a change which does not.
I	How much energy?	This theme contains quantitative activities on energy. A number of them are intended to give pupils a 'feel' for the amounts of energy, and rates of energy flow involved in various changes. The rest concern working out fuel costs in everyday situations – e.g. keeping a home warm, or running a car.
J	Flows of matter and energy	This theme is concerned with 'steady states' and how they are kept going. Pupils are encouraged to reason that steady-state systems, such as ecosystems or food chains, are kept in balance due to a constant flow of matter and/or energy through them, which itself is driven by changes which 'just happen by themselves'.

Table 2.2 *Project's activities - themes and content*

A typical activity of the project consists of a set of changes and a set of relevant abstract pictures, and pupils are asked to make appropriate matches. The purpose of this is to encourage pupils at the start to pay attention to important features of phenomena, then later to draw similarities between features of different phenomena, eventually leading them to see the few underlying principles involved. Most of the activities emphasise group activity and discussion, but they could also be used for individual work (Boohan and Ogborn, 1996a – 'Activities for the classroom').

Finally, the abstract pictures used in the activities tend to become more abstract as children progress through the activities.

"Initially, the abstract pictures show more specific aspects of the changes represented; later the pictures used are more generalised and each relates to a wider range of changes." (Boohan and Ogborn, 1996a – 'Activities for the classroom', p1)

2.7 From the project to the research

The key issues which arise from the above-described teaching approach in relation to the research questions of this study are:

- The idea of accounting for changes in terms of the destruction (and creation) of differences.
- The use of abstract pictures and corresponding vocabulary to represent changes.
- The importance of identifying similarities and differences between changes in terms of what is happening to the particles and the associated energy.

CHAPTER 3

Energy and Change in the Literature

3.1 Introduction

This chapter will aim to give a theoretical background to the research by reporting on other relevant published work. The work to be discussed is broadly concerned with children's ideas about energy and change. There is also extensive literature on teaching approaches to energy and change. These have helped me form a critical understanding of the project's approach, but are not discussed here. References to this work are included in the references and bibliography section of the thesis, marked with an asterisk.

The topics to be reviewed in this chapter include children's ideas about the particulate nature of matter, about specific processes of change and about energy. These topics have been extensively discussed in the educational literature. The review, however, will be selective; its purpose is to sketch out in broad general lines those issues that were thought to be relevant to this study. Only those studies are reviewed which report on pupils' conceptions of the ideas explored in the materials used in the teaching intervention.

More generally, the relevance of pupils' ideas (about the identified topics) to this study should be thought of as having at least four aspects.

- Knowledge of these pupils' ideas affected the development of the project's teaching materials. The authors of the materials were aware of them, and this awareness is reflected in the pupil activities they created.
- Knowledge of these ideas affected the design of this research study. Being aware of the issues that might arise in the course of the teaching intervention, I had to make sure that the tools used in the investigation would permit them to surface.
- This awareness also helped shape my expectations about what kinds of results I might get in the analysis, and further helped me to identify these results when they emerged.
- Finally, knowing the difficulties the pupils might have with the taught ideas, helped me to evaluate better the learning outcomes of the teaching intervention, and to recognise what might count as success.

The studies reviewed can be classified into two categories:

- studies concerned with pupils' ideas about matter and change; and
- studies concerned with pupils' ideas about energy and change.

Special consideration was given to include in these categories studies which make reference to ideas related to the Second Law of Thermodynamics, such as heat, temperature, entropy, reversibility, spontaneity, etc..

3.2 Matter and Change

Children's ideas about matter and its changes have been the subject of considerable research in recent years and there are a number of reviews of this work (Andersson 1986, 1990; Barker, 2000; Driver, 1985; Driver *et al.*, 1994; Garnett, Garnett and Hackling, 1995; Krnel, Watson and Glažar, 1998; Wandersee, Mintzes and Novak, 1994).

3.2.1 Concepts of matter and substance

Many researchers have investigated pupils' ideas about the particulate nature of matter (see for example, Brook, Briggs and Driver, 1984; Haidar and Abraham, 1991; Gabel, Samuel and Hunn, 1987; Johnson, 1998a; Lee *et al.*, 1993; Meheut and Chomat, 1990; Mitchell and Kellington, 1982; Novick and Nussbaum, 1978, 1981; Nussbaum, 1985; Pereira and Pestana, 1991; Renstrom, Andersson and Marton, 1990; Sequiera and Leite, 1990; Westbrook and Marek, 1991). As they have documented, these ideas concern:

- the nature and characteristics of particles;
- the 'space' between particles and the way particles are arranged;
- forces / attractions or bonds between particles;
- the intrinsic motion of particles.

The broad picture that emerges from this work is that pupils have a poor grasp of particle ideas even after having been taught about the relevant scientific model over a number of years.

Johnson (1998a) points out that typically around a fourth of the pupils in these studies gave responses in macroscopic terms even when they were prompted to think in terms of particles. Also, many pupils attribute the macroscopic properties of substances to particles at the microscopic level, for example suggesting that particles would melt, would get hot or change size.

Faced with this situation, some researchers, but not all, have suggested using the concept of 'substance' as a helpful bridge from the macroscopic to the microscopic

explanations. There are at least three reasons that have been given for this. One reason is that the notion of ‘substance’ relates more closely to pupils’ own experiences. A second is that it is more in line with the way pupils’ conceptions of matter seem to develop; more particularly, it is closer to their idea of ‘homogeneous continuous substance’, which they develop before they understand anything about particles. Renstrom *et al.* (1990) and Johnson (1998a) have proposed that students’ conceptions of matter progress from a ‘homogeneous and continuous substance’ view, through ‘substance units’ and ‘particle units’, before achieving a conception based on ‘systems of particles’. Finally a third reason is that the concept of ‘substance’ helpfully combines concepts of ‘element’, ‘compound’ and ‘mixture’.

However, it has to be recognised that children’s use of ‘substance’ is not fully in line with the scientific usage. They do not on the whole understand the concept ‘substance’ in terms of the properties of the substance. For example, iron nails and iron powder are judged different substances, on the basis of their appearance. Also pupils have no real idea of ‘pure substances’.

Quite a few attempts have been made to understand the meaning pupils give to ‘substance’, and to propose teaching sequences which take this into account (see for example, Ahtee and Varjola, 1998; de Vos, 1990; Johnson, 1996, 2000; Loeffler, 1989; Vogelezang, 1987). These sequences vary somewhat in what they identify as ‘substance’, and in what aspects of the concept of ‘substance’ they emphasise. For example, Johnson (1996, 2000) reserves the concept of ‘substance’ for talking about elements and compounds and uses the concept of ‘material’ to include the notion of ‘mixture’. Vogelezang (1987) on the other hand, suggests a progression in the use of the substance concept from the notion of ‘homogeneous substance’ to the concept of ‘one’ or ‘pure’ substance.

There is support from much of this research for teaching the distinction between ‘object’ and ‘substance’. Krnel *et al.* (1998) ascertain that children’s understanding of matter including its classification and composition, and physical and chemical transformations is influenced by the extent to which they are able to distinguish between ‘objects’ and ‘substance’ (which they call ‘matter’).

The project’s approach promotes the teaching of this distinction explicitly in one of its activities, which bears the name ‘Objects and substances’ (Activity C4). According to the teaching notes, in the materials the term ‘substance’ is used to mean both ‘pure’ substances and mixtures. However, it is rather the case that the term ‘substance’ is reserved to mean ‘pure’ substance, most of the time; in the representations used for a ‘mixture’ the (usually) two substances mixed together are

always identifiable, even when the representation is a continuous (as opposed to a particulate) one.

3.2.2 States of matter

Several researchers have investigated pupils' ideas about the three states of matter, with more emphasis paid to the 'gas' state (for example, Johnson, 1998b, 1998c; Jones and Lynch, 1989; Novick and Nussbaum, 1978, 1981; Séré, 1985, 1986; Stavy, 1988; Stavy and Stachel, 1985).

A common observation is that on the whole children decide on the state of a material based on its appearance and its behaviour. More particularly, the classification of solids and liquids is clear to children, but only in the more clear-cut cases. Viscous liquids are hard to classify - water appears to be the prototypical liquid -, and the same is true for soft solids and powders. In the case of powders there is an extra difficulty, since the fine powder grains are often confused with the 'particles', in the sense of atoms and molecules.

The identification of gases causes special difficulties for children since most of those commonly experienced, like air, which research suggests is the prototypical gas, are invisible and have no perceptible weight. On the other hand, knowledge of gases is necessary for understanding a number of processes such as combustion and evaporation. Consequently, as mentioned before, considerable emphasis has been put on researching pupils' difficulties with gases and their properties, as well as in developing teaching sequences to tackle these difficulties (see for example Andersson and Bach, 1996). From the findings of these researches it is worth mentioning two, which are particularly applicable to this study. One concerns pupils' ideas about the distribution of a gas; these would play a role when learning about the spreading out of gases, which is an objective of the project's approach. The pertinent research findings (Novick and Nussbaum, 1978, 1981) suggest that although increasingly with age pupils seem to favour a uniform distribution for a gas, they do not arrive at this using the idea of particle motion, and thus do not reason similarly when an operation is performed on the gas.

Another interesting result is Séré's (1985, 1986) concerning the conservation of amount of air when volume changes. This idea was found to be easily understood by 11-12-year-old pupils. The relevance here stems from the fact that some of the arguments the pupils used to explain this conservation related to the idea of reversibility. That is, they reasoned that since the change of volume could be fully reversed, the amount of air had to remain the same in spite of the change.

Finally, the project's materials, acknowledging explicitly that changes involving gases are more difficult for pupils to think about than those with solids and liquids, have assigned some of the early activities on matter to learning about the nature of gases and changes to it.

3.2.3 Changes to matter: physical and chemical

Useful work has been done on categorising children's explanations of specific physical and chemical changes. Andersson (1986, 1990) and Brosnan (1990) produced a synthesis of these categories in a broader scheme which could characterise children's thinking of material change in general. Since then, Andersson's scheme has been used extensively in research studies. It identifies the following five categories:

- Disappearance: No new substance is made - the original substance is seen as being used up, and/or as disappearing.
- Displacement: A 'new' substance appears simply because it has been moved from another place.
- Modification: A 'new' substance appears because the original one has changed form.
- Transmutation: The original substance is thought of as being transformed into a completely new substance. Some changes are also described in terms of transmutation of substance into energy, or of energy into substance.
- Chemical change: New substances are formed by the dissociation or recombination of particles in the original substances.

3.2.3.1 Changes of state – Melting, freezing, evaporation, condensation

Researchers who have reported pupils' ideas about changes of state include Bar and Travis (1991), Driver (1985), Driver *et al.* (1994), Osborne and Cosgrove (1983) and Stavy (1990a, b).

A common observation is that pupils' explanations seem to rely heavily on what is immediately perceptible. For the changes of melting and freezing this further means that they fail to appreciate that during a change of state the substance stays the same, even though its appearance changes. For the changes of evaporation and condensation, on the other hand, this reliance on the visible means that pupils often reason that liquids disappear or go somewhere else during evaporation and equivalently find it hard to identify the provenance of liquid in condensation.

On the whole, pupils' explanations of melting and freezing seem to be considerably less problematic than their explanations of other state changes. In particular, the state change of solid-ice to liquid-water appears to be the more straightforward for pupils, and seems to work as a prototype for the process of melting. Moreover, the reversibility of this state change of water was reported by Stavy and Stachel (1985) and Stavy (1990b) to be acceptable by almost all respondents (aged 6-15), whereas the same notion for candle wax was understood by only half approximately of 10-11-year olds, rising to 100% only at age 15. Commenting on this last result, however, Ferracioli Da Silva (1994) makes the point that depending on the way the interview was carried out the pupils may have interpreted the question to refer to the reversibility of the melted wax *object*, rather than the melted wax *substance*. Such an interpretation would explain why some children did not recognise that the freezing of wax is spontaneous and why they maintained that it can be done only with magic or by a machine.

The concepts of evaporation and condensation refer to changes involving the gas state, and thus present more difficulties to pupils. Several researchers have attempted to record these difficulties (Bar and Galili, 1994, Bar and Travis, 1991; Beveridge, 1985; Johnson 1998b, c; Levins, 1992; Osborne and Cosgrove, 1983; Russell and Watt, 1990; Russell, Harlen and Watt, 1989; Stavy, 1990a, Tytler, 2000).

Overall, all the researchers agree that an understanding of the gaseous state of matter is critical to an understanding of these phenomena.

Differences have been found in children's conceptions of evaporation depending on the context in which evaporation was seen as happening. Some researchers have distinguished in particular between evaporation at boiling point and at low temperatures, and have claimed that the former, its products (steam) being perceptible, is more readily understood by younger children. Johnson (1998b, c) questions this assumption, stating that although the visible mist above a beaker of boiling water may be a cue that water is leaving this way, "*it says very little about children's understanding of a liquid changing state to a gas in terms of what a gas is*". According to him, only the introduction of particle ideas can support and help establish the idea of a liquid substance itself becoming a 'body of gas' just like the air.

The reverse process, that is condensation, seems to be an even more difficult conception, since it requires children to reason that there is water vapour in the air. Not surprisingly, when the provenance of vapour was obvious as in the case of boiling water, the children had no problem accounting for the process. When

however, it was not as obvious, they found it hard to do so, even though they still understood that vapour can be changed into water.

Most of the above mentioned studies were also concerned with pupils' abilities to conserve matter in evaporation. Stavy (1990a, b) in particular was interested in whether there is any relationship between weight conservation awareness and the understanding of reversibility. She found that whereas the latter is not a pre-requisite for the former, there is some correlation between the two, specially in cases in which there are no supporting perceptual elements, or during ages when these elements do not serve as supporting entities.

The project's approach concerning the teaching of changes of state, is to put emphasis on the temperature changes which drive them and on the subsequent changes in the concentration of matter. There are very few studies which concentrate on these ideas, although several mention in passing that 'heat' was thought of as a cause of the state changes observed. I will mention two of them, which bear closer relationship to this research.

Abraham *et al.* (1992) tested 247 eighth-grade students in Oklahoma on five chemistry concepts after teaching. One of them was the state-change concept, and in particular the idea that 'heat energy is needed to change the phase of a material'. Students were shown with the help of diagrams what happens to the temperature of an ice cube as it is heated. They were then asked to explain why the temperature remains the same from the time the ice cube starts melting until it has completely melted. They were required to indicate that "*heat energy was used to change the ice to water and not to change the temperature*". Only 2% of the students showed any level of understanding of this concept.

Russell *et al.* (1989) describing pupils' explanations about the evaporation of water from a tank, assigned by them to the category 'Change of location with no physical change in the nature of the water', hint at ideas pupils may have about what drives evaporation. All of these ideas involve the action of a direct or an indirect agent, which may be human (or animal), or not. The sun, for example, might be identified as the agent which 'sucks the water' or which 'acts as a magnet and brings the water up [to the clouds] drop by drop'.

3.2.3.2 Dissolving – Mixing - Diffusion

Several researchers have studied children's conceptions of 'dissolving', and how these change from an early age to adulthood (for example, Blanco and Prieto, 1997; Cosgrove and Osborne, 1981; Driver, 1985; Longden, Black and Solomon, 1991; Prieto, Blanco and Rodriguez, 1989; Selley, 1998).

In explanations about dissolving, children again rely heavily on perceptible cues. They find it hard to see what *kind* of process dissolving *is*, and thus sometimes use ice melting as a prototype for dissolving. Using Andersson's scheme, pupils' responses can be categorised as displacement, transformation and disappearing. (Krnél *et al.*, 1998).

Few studies have been concerned with the question of the conservation of the solute. Their results suggest that pupils may not perceive the solute as a conserved quantity. However, their findings seem to me inconclusive since most of them seem to rely on a literal interpretation of the word 'disappear' used by pupils to describe what happens to the solute during dissolving. This term though used in an everyday sense could just mean that the solute has disappeared from sight, as some of the researchers themselves point out. Selley (1998) suggests that the most successful way to dispel pupils' conception that the solute disappears, is to show them that the solute can be recovered by evaporation, in other words to show them that the process is reversible.

The project's materials deal with this issue by explicitly provoking discussion about whether the solute 'disappears' or not when it dissolves in a solvent, in one of its activities ('Pictures of mixing' – Activity A2).

Another point that emerges in the literature is that pupils tend to focus on only one of the substances (usually the solute) that participate in dissolving, and regard the other (the solvent) as the agent of the observed change. In other words they do not appreciate the interaction between the liquid and the solid. The above-mentioned activity of the project deals with this issue as well. In its teaching notes it is stated that pupils should be encouraged to pay attention both to whether the substances are 'spreading out', and to what they are 'spreading out' into, that is to both the solute and the solvent in processes of dissolving.

Coming back to the notion of causal agents for the dissolving process, it has been reported that pupils perceive stirring and temperature as such agents. However, they do not hold an explanation of how these two factors affect the process, and thus they often reason that the change will be reversed or stopped when the agent stops acting. In the project's materials dissolving is presented as a change which 'just happens', because as a result of it matter is spreading out; factors such as stirring and temperature (differences) help by speeding up this spreading out.

Mixing is treated very similarly to dissolving in the project's materials. The focus again is on the fact that it is a spontaneous process which results in the spreading out of matter. The spontaneity of mixing seems to be very much in line with how pupils think about this process. Johnson (2000) found out that in his study pupils' application of mixing ideas was almost exclusively in terms of mixing up; "*the idea*

that a sample was already mixed and then might un-mix was not a part of the thinking". Again gases might be an exception to this result. Séré, describing images that twenty French children aged 12 associate with air, reports that over half of them thought that two gases would mix only at the boundary between them.

Only a few studies have been conducted on children's understanding of diffusion (for example, Simpson and Marek, 1988; Westbrook and Marek, 1991). The latter study examined children (across the age range) for understanding of the diffusion of a dye in water. Misconceptions here included a variety of alternative views about the diffusion process – for example that the dye will be unevenly distributed, or that it could spontaneously unmix. The authors do not give details of the frequency with which these views were held, but were they to be widespread, they would have potentially serious implications for the efficacy of the project's teaching materials since these *use* the spreading out of dye as the metaphor to explain the diffusion of energy (see 'Concentrated energy' - Activity E1), and do not discuss its nature, assuming that it is understood.

3.2.3.3 Chemical change

There is a vast literature on learners' ideas about the nature of chemical change (see for example Abraham *et al.*, 1992; Ahtee and Varjola, 1998; Andersson, 1986, 1990; Barker, 2000; Barker and Millar, 1999; Briggs and Holding, 1986; Brosnan and Reynolds, 2001; de Vos and Verdonk, 1985; Driver, 1985; Driver *et al.*, 1994; Garnett *et al.*, 1995; Hesse and Anderson, 1992; Johnson, 2000; Loeffler, 1989; Schollum, 1981a; Stavridou and Solomonidou, 1989, 1998; van Driel, *et al.*, 1998). Overwhelmingly, these studies have revealed that secondary school pupils have considerable difficulties understanding chemical change as substances reacting to form new substances.

There are many different kinds of difficulties about the nature of chemical change. At the macro-level there is real scientific difficulty in identifying chemical change. (One has only to remember that in early history oxides were treated as elements and metals as compounds.) Since pupils rely on the whole on perceptual changes to decide about the nature of a change, they tend to identify a chemical change by unusual and unexpected happenings: fizz, explosion or change of colour. Only rarely, however, do they also conceive these happenings as indicators of changes of substances into other substances.

Even when pupils do identify the appearance of a new substance, they often see it as the result of 'modification' or 'transmutation' (in Andersson's categories) of the

original substances; in other words they do not appreciate that the original substances may interact and combine to form the new one.

Reversibility has often been suggested as a macroscopic criterion for recognising chemical change, especially in early teaching (see for example the English National Curriculum for Science Key Stage 2 – DfEE/QCA, 1999). Stavridou and Solomonidou's (1989) general conclusion was that children who used the reversibility criterion were able to distinguish between physical and chemical changes. There have also been, however, many objections to the usefulness of this criterion: Stavridou and Solomonidou, for one, recognise that children's appreciation of reversibility depends on their knowledge of laboratory procedures for making a change 'come back' to its initial condition; Johnson (2000) contests the scientific accuracy of the criterion; and Andersson (1986) does not believe that it is *possible* to understand the notion of reversibility of chemical reactions at the macroscopic level. Moreover, Maskill and Cachapuz (1989) suggest that pupils may have problems with the meaning of the word 'reversible'. Using a word association test, they found that more than half of a sample of 30 14-year-olds did not see the term 'reversible' as related to matter changing back and forth in changes, but as referring to something that moves forwards and can also move backwards, rather like a car.

The researchers, who question the effectiveness of the reversibility criterion, note instead that the concept of a 'substance' is the prerequisite for constructing the chemical change notion. Johnson (2000) in particular stresses that without an understanding of this concept "*the pupils have no means of recognising the possibility that substances might change into other substances*".

Finally, all the researchers agree that an appreciation of the atomicity of matter is critical to an understanding of chemical change. In other words, the micro-level explanation of chemical change is essential. Johnson (in Buck *et al.*, 2001), however, reminds us the non-triviality of getting pupils to construct these explanations, when he forewarns that holding an incorrect particle model, in which particles have *macroscopic* character, would *inhibit*, rather than facilitate, an understanding of chemical change.

In the project's materials, chemical change is first introduced as a change in which new substances are formed. The very first activity intended to be used for this purpose is one ('Wearing out' – Activity F2) in which pupils are encouraged to make the distinction between changes to objects and changes to substances. The three subsequent activities are intended to give pupils experience in thinking about changes with the support of particle pictures, which show changes to substances as changes in the shading of particles. The idea of reversibility is brought in in the

following two activities, not as a criterion for the distinction between physical and chemical change, but in relation to spontaneity, the message being that changes in which matter is spreading out are difficult to reverse. Finally, only then do the project's materials explain chemical change in terms of particles joining, splitting or re-combining. Even then however, the materials do not give details about particular chemical changes in terms of atoms and molecules – such material is thought of as being readily available in existing textbooks, which may be appropriately used alongside the materials.

3.2.3.4 Burning and rusting

One important type of chemical reaction is a combination reaction. Burning and rusting are two such reactions which have been thought of as holding special interest by many researchers of pupils' alternative conceptions (for example Andersson, 1986, 1990; BouJaoude, 1991; Driver, 1985; Driver *et al.*, 1984, 1994; Meheut, Saltiel and Tiberghien, 1985; Prieto, Watson and Dillon, 1992; Ross, 1991, 1993; Schollum, 1981b; Schollum and Happs, 1982; Watson and Dillon, 1996; Watson, Prieto and Dillon, 1997). One reason for this is that both reactions involve the participation of a gas, and I have already discussed some of the problems that this entails for the pupils.

The broad picture that emerges from this work is that most pupils are unclear about the role of oxygen in both reactions. Oxygen is often not noticed at all, being invisible. On other occasions it is seen as enabling the process, but not participating actively in it. In these cases pupils identify the necessity for oxygen, but do not see this as interacting with the other substance.

On the whole, the research suggests that pupils' understandings are based on their everyday experiences with burning and rusting; they focus on the perceptually obvious features of the changes, and do not seem to have a generalised view of either process. Concerning pupils' account of burning in particular, several researchers have found it to be inconsistent and task specific. According to Meheut *et al.* (1985) there are two kinds of transformations that pupils identify in relation to burning, and these depend on the nature of the burning substance. In the first kind, substances such as metals, wax, water and alcohol are seen as changing only in form or state, that is they are seen as being 'modified' (in Andersson's terminology). The reversibility of this kind of transformation is sometimes mentioned. The second kind includes transformations in which substances such as wood, cardboard and candle wick are seen as changing into another substance or nothing, that is as being 'transmuted' or

as ‘disappearing’ (in Andersson’s categories). There is no question of the reversibility of this kind of transformation.

An extra feature of the process of burning, compared to other chemical reactions is that it gives off energy as heat. As a result, some pupils appear to view heat as a product of the reaction, giving it thus quasi-material dimensions.

Finally, the researchers seem to agree that key ideas that pupils need to consider in order to develop a ‘chemical reaction’ explanation (in which new substances are formed by the dissociation or recombination of particles in the original substances) for burning and rusting include conservation of matter and weight, the particulate nature of matter and the role of gases in chemical changes.

As a result of this discussion, it comes as no surprise that the project chose ‘heating copper’ as the ‘case-study’ to focus on, when introducing chemical change as a re-arrangement of particles. Although this choice is nowhere explained in the materials, a close examination of the relevant pupil activity (‘What happens when new substances are made?’ – Activity G4) suggests that its authors were aware of the special difficulties this change (i.e. a chemical change involving a gas and heat) might present to pupils, and wanted to address them explicitly. In particular, the activity asks pupils to choose from six particle pictures the one which best represents what happens when copper is heated in air, and to explain their choice, as well as what the other five pictures show and why they did not choose them. In essence the activity requires pupils to: distinguish between the representations of a solid and a gas (in terms of spatial arrangement of particles); distinguish between the processes of mixing and chemical reaction; reason about the specific chemical reaction between copper and oxygen in terms of particles joining together; and identify that the number of particles for each of the reactants is conserved.

3.2.3.5 Energy, chemical change and spontaneity

Pupils’ ideas about energy are discussed extensively in section 3.3; here, I will refer only to the ones which are related to the understanding of chemical reactions. Only a few studies have reported on these ideas (see for example Barker, 2000; Barker and Millar, 2000; Boo, 1998; Gayford, 1986; Holman, 1986; Novick, 1976; Ross, 1993, Taber, 2000a).

The basic alternative conception here that many pupils hold is that energy is released when chemical bonds break. Barker’s (2000) longitudinal study presents evidence that this idea persists even among post-16 students of chemistry. Ross (1993) suggests that this conception arises because pupils learn that ‘fuels contain energy’, and thus associate chemical bonds with an energy-storing role. He thus proposes that

in teaching about combustion and respiration energy should be associated with the fuel-oxygen system, rather than only with the fuel. Boo (1998) gives a more general explanation for why pupils believe this. He suggests that since in everyday language energy is said to be indispensable for making things happen, pupils think that ‘making bonds’ must also require energy, which is then released when the bonds are broken.

I have already mentioned in chapter 2 (section 2.5.1) that the project chose to represent a chemical bond as a ‘spring’, which appears to ‘stretch’, or ‘collapse’ (to its normal size), depending on whether it stores or releases energy. (A similar suggestion for teaching about energy and chemical change has been made by Ross (1993)). According to Holman (1986) however, children seem already to conceive of bonds as springs, only not as represented by the project, but as *coiled* springs “*ready to unwind and release energy*”. Were his observation accurate, it would have implications for the accessibility and effectiveness of the project’s representations.

Pupils’ ideas about the spontaneity of chemical reactions are examined by even fewer studies, perhaps because the idea of spontaneity is traditionally only met by pupils in post-16 chemistry lessons. A reported misconception in this area is that endothermic reactions cannot be spontaneous (Johnstone, MacDonald and Webb, 1977). A source of this misconception may be that often in chemistry classes pupils are given as a reason for why a chemical reaction happens that the products of the reaction are at a lower energy than the reactants. This account however, does not explain why a reaction takes place; it does not predict which reactions are going to happen and which are not, nor does it explain why in some reactions reactants are not entirely converted into products. According to Taber (2000a) such an account on its own “*just gives a different-sounding mode of description*” for *what* is happening, rather than an *explanation* for *why* it is happening.

Ribeiro, Pereira and Maskill (1990) also found that even fourth year undergraduate chemistry students who knew the scientific criterion for spontaneity, did not use it to decide whether or not a chemical reaction had taken place, unless they were asked to. Moreover, even when they used it, they did not always abandon their natural interpretation, which was that a reaction is spontaneous only ‘if we do not need to interfere’. In the case of ‘paper burning’ for example, twelve out of the fourteen students judged that it was not spontaneous, and only two of them changed their mind when faced with the results from the calculation of the ΔG value.

The project’s materials attempt to tackle these issues explicitly. They first establish the idea of spontaneity in relation to mechanical and gravitational springs, which are more intuitive contexts, and then extend it to ‘chemical springs’. Moreover, in the

relevant teaching notes they advise the teachers when they say that these changes ‘just happen’ to add ‘once they have been started’. In the project’s words:

“This is an important idea to be clear about since it causes confusion for pupils when they are thinking about changes to fuels, which often have to be set alight before they burn.” (Theme H, p5)

3.3 Energy and Change

Children’s ideas about energy have been enormously studied in the last thirty years and more particularly in the 1980s, and there have been a number of attempts to propose teaching sequences, which take these ideas into consideration. Also, there are a number of reviews of this work (see for example, Brook, 1986; Driver *et al.*, 1994; Duit, 1986; Welch, 1985). In this section I will give a condensed overview of the meanings children give to the term ‘energy’, and of their use of the concept in accounting for changes. A more detailed discussion of children’s conceptualisations of energy as well as of the different approaches to teaching the concept can be found in my MA dissertation (Stylianidou, 1992), with the title ‘What is involved in understanding energy?’.

3.3.1 Pupils’ conceptualisations of energy

This subsection will discuss children’s conceptions of energy. As a way of organising this discussion I will present these conceptions under the following seven subheadings, which reflect some of the main alternative frameworks identified in the educational literature (see Watts, 1983; Brook and Driver, 1984).

- a. Energy in an anthropocentric or animistic framework.
- b. Energy confused with other physical quantities.
- c. Energy identified with a process.
- d. Energy as a cause of activity.
- e. Energy as an ingredient or as a product.
- f. Energy as a fuel.
- g. Energy as a substance which flows.

a. *Energy in an anthropocentric or animistic framework*

Several studies (for example, Black and Solomon, 1983; Bliss and Ogborn, 1985; Brook, 1986; Brook and Driver, 1984; Finegold and Trumper, 1989; Solomon, 1983a, 1992; Trumper, 1990a; Trumper and Gorsky, 1993; Watts 1983) have

reported that young children associate energy with living things, mainly with human beings. Finegold and Trumper (1989) suggest that this framework is used with decreasing frequency with age and after the study of physics.

Indeed, Solomon (Black and Solomon, 1983; Solomon, 1983a, 1992) found very strong ‘living’ associations for the word ‘energy’ prior to teaching. Moreover, she observed that as children get older their responses change from ‘vitalist’, that is linked to health, growth and life, to ‘human kinetic energy’ ones concerned with sport, activity, feeling tired and food. Other researchers have also noted the everyday-language sense of ‘energetic’ occurring in interviews about energy (see Brook, 1986). According to Solomon (1983a, 1992), such a view of energy may mean that children give to energy *quality* characteristics, one of which is lack of measurability. Correspondingly, she found that only 28 per cent of those who gave entirely human associations for energy thought it might be measurable, compared with 72 per cent of those giving at least one non-human example.

In response to these kinds of results, Bliss and Ogborn (1985) caution against interpreting children’s explanations solely in terms of animacy, and point out that explanations in terms of activity may be easily perceived as animacy, since animacy and activity are properties shared by many situations and thus confounded.

b. Energy confused with other physical quantities

Research suggests that children easily conflate the meaning of energy with undifferentiated notions of force, work and power even after teaching (see for example, Ault, Novak and Gowin, 1988; Brook and Driver, 1984; Duit, 1984; Gair and Stancliffe, 1988; Goldring and Osborne, 1994; Solomon, 1992; Trumper and Gorsky, 1993; Viennot, 1979; Watts and Gilbert, 1983). A reason suggested for this is that in everyday language all four terms are used interchangeably with no contradiction or ambiguity.

What, in particular, links the concepts of force and energy is that both are seen as enabling things to happen. Viennot (1979), for example, noted that in some situations pupils used the concept of energy to mean the same as ‘supply of force’, a notion often used, according to her, by pupils to account for the existence of motion.

c. Energy identified with a process

Some pupils identify energy only when there is an overt display of activity, and equally reason that a situation does not need or use energy when there is ‘absence of activity’ (see for example Bliss and Ogborn, 1985; Brook and Driver, 1984; Finegold and Trumper, 1989; Watts, 1983). Finegold and Trumper (1989) suggest that this

framework is used increasingly after studying physics. There are suggestions that it as well stems from the everyday usage of the word ‘energy’ and thus is not equally prevalent amongst pupils from different countries (see for example Duit, 1984; Koliopoulos, Tiberghien and Psillos, 1992).

On the other hand, Bliss and Ogborn (1985) wonder whether this framework is not a by-product of the tools used in the research (e.g. the context of the situations, or the wording of the questions used), and energy is not really thought of as an activity, but rather as the cause of an activity.

d. *Energy as a cause of activity*

This framework suggests a notion of energy as a causal agent, as a source of activity, and as such stored in objects that possess energy. Some researchers have distinguished further within this framework, depending on whether energy is seen as simply residing in objects or as ‘causing things to happen’ (Finegold and Trumper, 1989; Gilbert and Pope, 1982; Trumper, 1990a; Watts, 1983). They found the latter sense one of the most commonly used by pupils of all ages.

Shultz and Coddington (1981) report that research on the development of causal reasoning has indicated that from the age of three until adulthood causation is understood in terms of generative transmission, that is of the notion that “*an effect event is actually produced or generated by virtue of some transmission emanating from the causal event*”. One might expect that such an understanding might help in the development of the energy concept, since in the field of physics (according to Shultz and Coddington) it is the transmission of energy from one system to another that explains the production or generation of physical events. In agreement with such a premise, Koliopoulos, Tiberghien and Psillos (1992) observed that the causal structure ‘agent-patient’ of this framework prompted pupils to consciously unify processes (electricity, heat(ing), motion) under the word energy. However, Shultz and Coddington’s findings suggest that children do not have more than “*a rudimentary appreciation of the concept of energy*”, and that an intuitive grasp of the laws of energy emerge only later in development. The ‘cause’ framework under discussion may be the result of combining the principle of generative transmission with an under-developed concept of energy.

e. *Energy as an ingredient or as a product*

In this framework, energy is seen as either a dormant ingredient within objects or situations, which needs a trigger to release it, or a product of some process (see for example Brook and Driver, 1984; Watts, 1983; Trumper, 1990a). The latter

conception is compatible with a ‘transmutation’ view of material change in Andersson’s (1986, 1990) categories (see discussion in subsection 3.2.3).

According to Finegold and Trumper (1989) and Trumper (1990a, 1991) this framework appears increasingly in pupils’ responses after studying physics. Moreover, pupils who held to a greater extent this framework and the ‘cause’ framework, seemed more successful in learning the accepted scientific concept about energy.

f. Energy as a fuel

In this framework energy is perceived to be substance-like, a fuel or a kind of fuel which is in short supply and which is used or consumed for our benefit (see for example Ault *et al.*, 1988; Brook and Driver, 1984; Duit, 1984, Solomon, 1992; Watts, 1983). This conceptualisation of energy has been probably reinforced by its use in ‘Save-it’ and ‘use energy wisely’ campaigns (Ross, 1993). Duit (1984) also speculated that this framework might be determined by language or cultural context, since he found it present in German pupils but not in those from the Philippines.

g. Energy as a substance which flows

Energy here is thought of as a weightless and substance-like fluid which flows in and/or out of an object. This framework is particularly evident when pupils describe electrical and thermal phenomena (see for example Brook and Driver, 1984; Watts, 1983). It bears strong similarities with the conception children hold of heat (see, for example, Erickson and Tiberghien, 1985). However, it was also noted by Gayford (1986) in biological contexts.

3.3.2 Changes and energy: pupils’ use of the ideas of transfer and conservation

In this part I will examine the issues which concern pupils’ use of the ideas of energy transfer and conservation in accounts of changes.

Overwhelmingly, research studies have revealed that pupils on the whole do not spontaneously use energy transfer ideas in their explanations (see for example, Andersson, 1999; Brook, 1986; Brook and Driver, 1984; Driver and Warrington, 1985; Koliopoulos *et al.*, 1992; Solomon, 1983b, 1992). Moreover, when they are prompted or asked to describe the flow of energy, they tend to describe the observable objects and events rather than the energy flow (Andersson, 1999). Having said this, when pupils do use this idea they seem to have little difficulty with it, and Koliopoulos *et al.* (1992) found that they are more likely to do so in relation to



electrical and to a certain extent thermal phenomena, than in relation to mechanical ones.

Research has also shown that pupils do not see a need to conserve or quantify energy (see for example, Ault *et al.*; 1988; Black and Solomon, 1983; Brook and Driver, 1984; Finegold and Trumper, 1989; Duit, 1981, 1984; Gayford, 1986; Shultz and Coddington, 1981; Solomon, 1985, 1992). When asked to analyse physical systems they tend to focus on the observable aspects of the phenomena or answer in terms of ‘lost’ or ‘used up’ energy. Moreover, even when pupils are able to use energy conservation ideas in their explanations, they rarely apply them to solve simple problems (see for example Driver and Warrington, 1985; Goldring and Osborne, 1994). Several reasons have been suggested for these results. One is the difference in meaning that the word ‘conservation’ has in everyday language. For example, Solomon (1992) reports that Greek speaking pupils who had no everyday-language use of the word ‘conservation’, *“all got its physics meaning correct both while speaking about it and in the test”*. A second, and perhaps more important, reason is that the conservation principle seems to contradict all common experience of a world in which irreversible changes with strong dissipative effects abound. On this point, Kesidou, Duit and Glynn (1995) have noted that pupils’ difficulties in interpreting dissipative changes in terms of energy conservation are also partly due to their lack of understanding of energy as an extensive quantity, and more particularly to their lack of differentiation between heat and temperature. Finally, Shultz and Coddington (1981) argue that *“direct perceptual experience is not sufficient for a belief in conservation of energy; it is necessary to have a conceptual grasp of the phenomenon”*, and this conceptual grasp is rarely realised before about 15 years of age.

3.3.3 Changes and energy: pupils’ use of ideas concerned with the Second Law

Compared to the number of studies that exist on pupils’ conceptions of many science topics (including the ones on energy already mentioned), only little information is available concerning children’s understanding of ideas concerned with the Second Law of Thermodynamics.

One of these ideas is energy degradation, and the related question is whether children understand intuitively the idea of energy degradation as part of the everyday meaning they hold of energy. Some researchers argue that they do (for example, Ross, 1988; Solomon, 1982) and mention expressions like ‘energy consumption’ or ‘useless energy’ as evidence. However, there is little empirical evidence on whether this is the

case. Brook and Driver (1984) report that the pupils in their study rarely used spontaneously ideas about energy degradation in their responses, even when they reasoned about ‘impossible’ changes. Moreover, Lijnse (1990) argues that in order to understand energy degradation one has to already have a good grasp of the conservation aspect of energy, which, as already mentioned, poses difficulties of its own to pupils. On the other hand, Black and Solomon (1983) found out that when the teaching of energy degradation preceded that of energy conservation, the percentage of pupils who answered in terms of energy transformation and dissipation rose from 15% to 40%.

Concerning the concept of entropy, Shultz and Coddington (1981) replicated and extended a Piagetian study on the idea of chance and found that whereas children from nine years of age showed some intuitive understanding of entropy, the concept was not fully grasped (intuitively) before about 15 years. In other studies the conceptual difficulties of older pupils studying thermodynamics were investigated (see for example, Johnstone, Macdonald and Webb, 1977; Lowe, 1988). Johnstone, Macdonald and Webb (1977) report that even after being taught about entropy most of the 16-17 year-old pupils in their study had only a superficial understanding of the concept. They often confused entropy with kinetic energy; they described it as a measure of randomness, or disorder in a system; they perceived entropy increase as equated with temperature increase, etc..

Some of the studies on heat and temperature, thermal equilibrium, heat conduction, and latent heat have also reported results on aspects of the basic ideas of the Second Law (see for example, Arnold and Millar, 1994, 1996a, 1996b; Engel Clough and Driver, 1985; Erickson and Tiberghien, 1985; Harrison, Grayson and Treagust, 1999; Kesidou and Duit, 1993; Kesidou, Duit and Glynn, 1995; Lewis and Linn, 1994; Thomaz *et al.*, 1995; Wiser and Carey, 1983). According to these studies, pupils’ have difficulties understanding thermal phenomena as thermal interactions; they often fail to recognise the boundaries of the thermally interacting systems and to take into account all their elements. Instead they tend to reason about temperature changes in an object solely in terms of its properties (size or material), or use/purpose to which it is put. Viennot (1998) explains this reasoning as ‘linear causal reasoning’, in the sense that each phenomenon is produced by a single action. This kind of reasoning, compounded by the difference in tactile sensations pupils experience with various materials at the same temperature, prevents them from seeing temperature equalisation as a general principle governing all thermal phenomena.

Pupils’ difficulties with the concept of thermal equilibrium has also been attributed by most researchers to their lack of differentiation between the concepts of heat and

temperature, since all three concepts are perceived as being interlinked and interdependent. The latter difficulty, on the other hand, has been largely ascribed to the different meanings associated with the word ‘heat’ both in everyday language and in science textbooks. Hence, various suggestions and/or teaching sequences have been put forward aiming at reducing pupils’ confusion over heat (see, for example, Beretta and Gyftopoulos, 1992; Carlton, 2000; Gailiunas, 1988; Heath, 1983; Mak and Young, 1987; Summers, 1983; Taber, 2000b; Thomaz *et al.*, 1995; Wiser and Amin, 2001). These vary from using the word ‘heat’ only as a verb to mean the transfer of energy due to temperature differences (Summers, 1983); to using it to mean primarily entropy (Herrmann, 1992), or only after energy and entropy have been introduced (Beretta and Gyftopoulos, 1992); to using two separate words ‘heat_e’ and ‘heat_s’ for the everyday and scientific meanings of the concept respectively (Wiser and Amin, 2001). On the other hand, in response to some of these suggestions, there have been other voices pointing out that

“[...] children need extensive opportunities to talk about and to reflect upon everyday and laboratory experiences of thermal phenomena if they are to separate the two ideas [heat and temperature] [...]. In so doing, they will inevitably use the word “heat” in its everyday sense, which encompasses both the notion of a stored quantity (internal energy) and of a quantity in transit (heat). We believe that a policy, on the teacher’s part, of systematically rephrasing children’s utterances to replace “heat” with some other, more acceptable term, will either pass largely unnoticed by the children or will become an additional source of confusion.” (Arnold and Millar, 1996b, pp252-253)

In the project’s materials the terms ‘heat’ and ‘heat energy’ are not endorsed; the teachers are advised, though not in a rigid way, to use the idea of energy transfer albeit expressed in any way pupils feel comfortable with.

Finally, there are few studies which aimed explicitly at exploring children’s conceptions of irreversibility (Duit and Kesidou, 1988; Ferracioli Da Silva, 1994; Kesidou and Duit, 1993). These studies point out that whereas most pupils reason that processes occur by themselves in one direction only, this reasoning is mainly based on commonsense rather than scientific conceptions. More specifically, Ferracioli Da Silva (1994) found that overall chemical and life processes are more likely to be seen as irreversible than are mechanical and physical changes. His study also points out the important role of action in commonsense reasoning about reversing a change. When pupils say that some process is reversible they often reason

in terms of a possible action that can be taken in order to reverse the process. This action can be unrelated to the one which caused the process to happen forwards, or can be the reverse of the initial action.

CHAPTER 4

Exploratory Phase: Developing Interview Structure and Method

4.1 Introduction

This chapter reports on the first phase of the research. This phase had an exploratory character and was concerned with the development of the main research instruments to be used in the study.

More particularly, at the time this first phase took place (January to June 1993), the project team was developing the idea of using abstract pictorial representations of changes in order to help pupils focus on the more generalised features of the changes, and their concern was to find out first whether and how children would make sense of these abstract pictures and second how these could be used in the classroom. The project team was also interested in detecting if the first teaching attempts - which were taking place concurrently - might have had any influence on children's perceptions of processes of change and their causes.

As this work is a study of the impact of the new teaching approach, these were also questions that concerned me. Further, at that time, I was in the process of developing the research instruments to be used in the main study (second phase of the research); that is I was deciding about the tools which could reliably detect the effects of the approach on pupils, and designing their structure. Working with the project team, to generate the kind of data they were interested in, would give me an opportunity to develop and refine 'in action' at least one of these tools, and so I did.

There were a number of ways one could have gone about this. For example, to investigate the success of teaching about energy and change using abstract pictures, the pupils could have been given a questionnaire, they could have been interviewed, or they could have been given appropriate science tests to see how well they performed compared with their peers taught using traditional approaches. In addition, most of these methods could have been used at various times; for example when the pupils were first introduced to the abstract pictures and/or after they had been taught using them.

The project team had already collected some information concerning pupils' reactions to the new materials from classroom observation and the pupils' written

work. They and I however decided that the principal weight of the evaluation would be carried by small-group task-based interviews. There were both theoretical and pragmatic reasons for this. Theoretically, interviewing the pupils when they were actually using tasks very similar (and in some cases identical) to the ones they had used (or would use) in the classroom, and doing this in small groups, as they would have done in the classroom, was felt to produce more 'authentic' data than say questionnaires or other methods. It was also recognised that this data would be produced in a considerably more controlled setting than a classroom situation. On the other hand, a group interview was hoped to be more motivating for children than a one-to-one interview and thus to encourage them to express their ideas spontaneously as well as to develop them extensively.

Small-group task-based interviews also appealed to the project team because they would allow them to try out (at least on a small scale) tasks, which would later in a revised form become part of the classroom materials. From my point of view, I hoped that a type of task-based interview would provide 'richer' data than other instruments and was keen to find out whether it could be used as the basis for the main study.

These reasons were also supported by pragmatic concerns. From the point of view of both the project team and myself, it was important that the views of all the pupils using the materials could (at least in principle) be ascertained. Given that a significant number of pupils had appreciable problems with written English (see section 5.3 for more details on this), using a written task would have raised additional barriers to their self-expression. An oral, task-based interview did not suffer from this limitation.

Consequently, Richard Boohan (co-director of the project) and I between us carried out thirteen 45-minutes interviews with pupils in groups of four (in total 52 pupils). These pupils were of average achievement, in the age range 11-15 years and came from London comprehensive schools.

4.2 About the interviews

This section contains information about the interviews conducted with each age group of pupils. The focus is primarily on the design of the interviews and how this evolved over time, as it was tried out, reviewed and improved. The analysis of these interviews was done by the project team and was included in an interim report to the Nuffield Foundation (Boohan and Ogborn, 1993). A selection of these interviews were also analysed in greater depth by myself. The findings of these analyses,

which are referred to in the following subsections, informed both the design of the interview tool as well as subsequent interviews in the main study.

4.2.1 Year 7 interviews

The first three interviews were carried out with twelve Year 7 pupils (in groups of four). At that point the idea of using abstract pictures to help pupils to abstract similarities between different situations had not yet been conceived by the project. Instead the idea then entertained was of having a set of ‘prototypical’ situations which pupils would study throughout the materials, and so over the long term become familiar with, and which they would later relate to less familiar real world situations in order to abstract common features. The interviews took place after children had completed a topic called ‘Solutions’ which had included activities on physical changes developed by the project. The interviews entailed identifying (by underlining) the changes mentioned in a text provided to them about ‘The Earth’ and matching these to a set of realistic schematic pictures. These pictures were thought of as ‘prototypes’ because they depicted physical changes such as cooling, warming, melting, freezing, evaporating, condensing, and dissolving, happening in familiar and everyday settings. The eight changes depicted were:

an ice cream on a hot day	a sugar cube in water
drying your hair	copper sulphate forming from solution
soup put into a freezer	a cold plate in a hot oven
a window next to a kettle ‘misting up’	a hot oven after being switched off

In the first interview, each pupil was asked in turn to match one of the changes (previously identified in the text) to one prototype, and then justify the match, while the other pupils had to say whether they agreed or not. We found out that on the whole no alternative matches were suggested by the pupils once the match was done by one of them. They also seemed to agree easily on the justification offered by their peer, waiting for their turn to come to do the matching. Thus in order to involve more pupils in the discussion of each of the changes and to increase the likelihood of disagreements arising, which could further incite interesting talk, the procedure was slightly modified for the remaining two interviews. Under the new design each pupil was given a pack of cards showing the ‘prototypical changes’; before the pupil whose turn it was to do the matching revealed her choice the other pupils had to put one of the ‘prototype’ cards down in front of them face down, the one they thought to be most similar to the change in question. In this way each pupil had to commit herself to a match before finding out the other pupils’ matches. The interviewer would then ask the first pupil to justify her choice, the ones who had the same choice to say whether they agreed with the justification and the ones who had

chosen differently to explain theirs. The interviewer would also prompt children to talk about the differences between the situation and the ‘prototype’. This new interview structure proved successful in at least two ways: it increased the kinds of matching which were considered, and secondly it provoked a good level of discussion among pupils as they tried to justify their choices.

One other thing that arose from these interviews, which later led to the idea of using abstract pictures, was that it is very difficult to have representations of these ‘prototypical’ situations which would be unambiguously seen as such, that is, which would not suggest irrelevant features to reason about. This realisation came from examining the justifications the pupils generated for choosing a particular matching. Whereas it was more common that pupils paid attention to the general features of the changes, in some cases they paid attention to surface similarities, which seemed to be suggested to them by the pictorial representations of the changes. For example, ‘ice cream melting’ was matched to ‘hail forming’ because *“It’s cold and it falls”*. The pupil seemed to reason in this way because the picture of ‘ice cream melting’ showed a cone of ice cream tilted on its side and dripping under a hot sun.

4.2.2 Year 8, Year 9 and Year 10 interviews

The interviews carried out with pupils in years 8, 9 and 10 were different in structure from those conducted with Year 7. In each of these three years, although the content of the interview varied, the structure of the interview was the same: they all included the use of abstract pictures and consisted of three tasks.

In the first task (called ‘grouping’ task) the pupils were given a number of situations (eight in Year 8, twelve in Year 9 and 10 interviews), and were asked to put them into groups of similar kinds of changes, and explain the reasons for their groupings. The aim of this task was to find out what features of the changes children pay attention to spontaneously in making comparisons.

In the second task (the ‘teaching’ task) the pupils were taught (or reminded) of the conventions of a set of abstract pictures. The aim of this task was to ensure that the pupils were conversant with the meaning of the abstract pictures to be used in the third (‘matching’) task.

Finally, in the third task (the ‘matching’ task) the pupils were given the same situations as in the ‘grouping’ task and were asked to match each in turn to one of the abstract pictures, and to explain their reasoning. As in the equivalent task of the Year 7 interviews, before each pupil made a match, the other pupils had to make their own choice by putting the appropriate numbered card face-down in front of

them. This had proved essential in order to explore to the maximum the potential of all the interviewees while keeping at the same time the task interesting and stimulating for them. If a situation now was matched to a picture which had previously been matched to another situation, the pupils were asked to explicate the similarities and differences between the two situations. The aim of this ‘matching’ task was two-fold: to see whether the abstract pictures succeeded in drawing children’s attention to the essential features of the processes of change, and furthermore whether the use of abstract pictures helped the pupils see similarities between different changes based on these essential features.

Where the interviews in the three years significantly differed was in the familiarity that the pupils had with the abstract pictures used in them. The teaching purpose of task 2, thus, differed accordingly in each.

Year 8 pupils had never used the pictures before and were therefore first introduced to them in task 2, which hence served the purpose of ‘teaching’ them as *new*.

Year 9 pupils had met some of the abstract pictures before, but not in any systematic way. In task 2 the pupils were both introduced to new pictures (to be used in the ‘matching’ task) and reminded of the old ones; task 2 served hence the purpose of ‘teaching’ them as *extension*.

Finally, Year 10 pupils had used the abstract pictures of the ‘matching’ task before and therefore task 2 served the purpose of reminding the pupils of them or of ‘teaching’ the pictures as *familiar*.

In the following subsections I discuss further the role of the ‘teaching’ task (task 2) for each year’s interviews and I give details about the teaching that had preceded them, as well as about the situations and abstract pictures used in them.

4.2.2.1 Year 8 interviews

The Year 8 interviews (four all together with 16 pupils in total) concerned thermal changes and entailed looking at energy flows and temperature differences in situations involving insulation. They took place after the children had completed a topic on ‘Energy’, which had included ideas from the ‘differences story’.

The situations used in the interview covered a variety of different objects - each in an insulated and a non-insulated instance - and of different insulators, as well as a range of temperatures with the objects below, above or at the temperature of the surroundings. These eight pairs of situations were:

situations	non-insulated	insulated
• hot chocolate left in a room	in a cup	in a vacuum flask
• cold lemonade in a warm room	in a glass	in a vacuum flask
• frozen food	left on a table	wrapped in newspaper
• coins at room temperature	left on a table	wrapped in a woollen bag
• hot water tank	without insulation	with insulation
• snowman on a freezing day	by itself	wrapped in a coat
• sun shining on a house	poorly insulated house	well insulated house
• water pipes on a cold day in winter	without insulation	with insulation

The procedure followed in the interviews has already been described above. Initially, pupils were asked to group the insulated examples and explain their choices. In the second task ('teaching' task), the pupils were introduced to the abstract pictures and had a chance to try out whether they had understood their conventions. Finally, in the third ('matching') task they were asked to match each pair of situations in turn to one out of a total of nine pairs of abstract pictures (an example of which is shown in Figure 4.1), and to explain their matches.

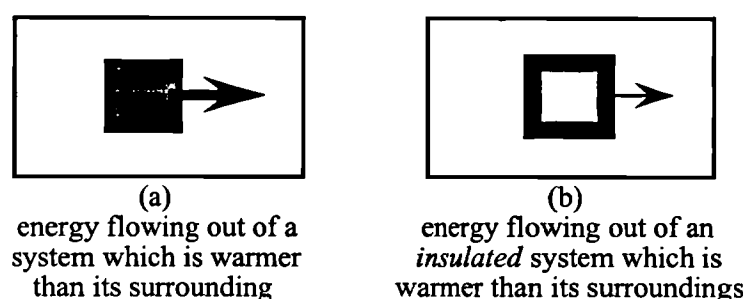


Figure 4.1 Example of abstract pictures used in Year 8 interviews

These were the interviews from phase 1 that I chose to analyse in greater depth, because of both their *structure* and their *content*. As was mentioned above, these interviews were different from all the others (in phase 1) in that the pupils were meeting the use of the abstract pictures for the first time. Since, as will be seen, all the pupils interviewed in phase 2 were taught the use of the abstract pictures in their science lessons prior to interview, this was the only situation in an interview in which I collected data as the pupils were being *taught* about the abstract pictures. Moreover, these interviews were concerned with representation of *energy flow*, the teaching of which was fundamental to the project. The paper (Stylianidou, 1995) detailing this analysis for task 3 ('matching' task) is attached as appendix 4.1.

In brief, the findings that arose from the analysis of these interviews are:

- In the 'grouping' task, pupils were able to find groups which fitted the examples, and no problem cases were raised. Pupils' justifications for these groupings were on the whole simple and brief; their focus was usually on relevant features of the

changes, though rarely on temperature differences. Moreover, not surprisingly, there was no mention of energy at this stage.

- In the ‘teaching’ task, pupils seemed to have no problems using and understanding the meaning of the abstract pictures.
- In the ‘matching’ task, there were many successful matches and all the pupils were able to give justifications for making their choices in most cases. These justifications all involved a much more sophisticated level of reasoning than in the ‘grouping’ task at the beginning. The pictures appeared to encourage them to pay more attention in their explanations to temperature differences and energy flows, even though some children had not differentiated the meanings of heat, temperature and energy. Moreover, when prompted by the pictures the pupils appeared to give more extended responses, even when these were not very clear. Good discussion also often arose from differences in choices of representations or even from failures in making these choices.
- Finally, due to lack of time, only a few pupils were asked in the interview to identify similarities and differences between situations matched to the same abstract picture. These few responses, however, indicated that using the abstract pictures had not effected a substantial shift in their reasoning in this respect compared to the initial ‘grouping’ task. On the other hand, the complexity of the task, which involved comparisons between two *pairs* of situations and two *pairs* of abstract pictures, combined with the pupils’ inexperience of using the abstract pictures could be responsible for this result.

4.2.2.2 Year 9 interviews

Four interviews were also carried out with Year 9 pupils (16 pupils in total). These involved looking at physical and chemical changes using abstract pictures of particles. The pupils who took part in these interviews had completed a topic on ‘Chemical Reactions’.

The situations used in the interview covered a range of physical and chemical changes which involved either one or two substances as reactants, including some in gaseous phase. These twelve changes were:

bending a metal spoon	using bleach to get rid of a stain on clothing	some wood burning
glue becoming hard	a glass bottle breaking	ice forming on a lake in winter
putting Alka Seltzer in water	using rust remover on an old car	washing the dirt off your hands
blood forming a blood clot	butter melting in a hot pan	a metal bracelet tarnishing

The procedure followed in the ‘grouping’ and ‘matching’ tasks was the same as before. In the ‘grouping’ task, the pupils were asked to put the above situations into

groups of similar changes; and in the ‘matching’ task, they were asked to match each of these situations to one of ten abstract pictures. Three examples of these abstract pictures are shown in Figure 4.2.

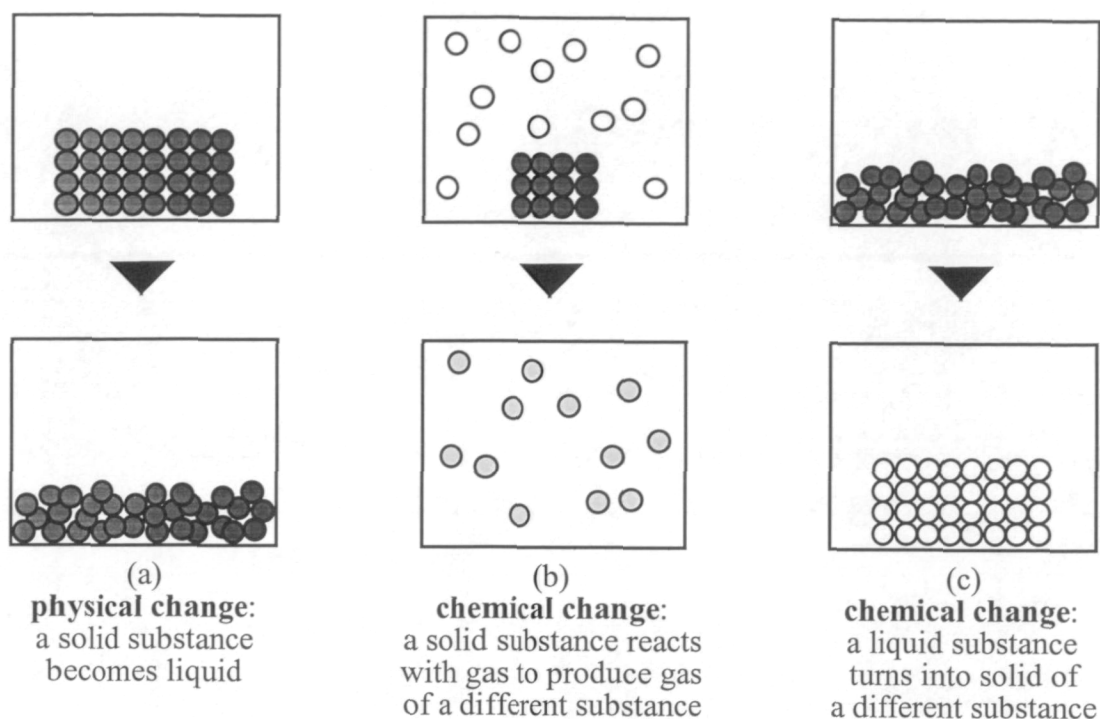


Figure 4.2 Examples of abstract pictures used in Year 9 interviews

The pupils had come across these kinds of abstract pictures in their lessons of the relevant topic. However, at that time these pictures were at an early stage of development and their use in the lessons had been neither systematic nor extensive. Moreover, the interviews took place almost six months after the end of the topic, so it was not expected that the pupils would have retained a lot from it. So, the second (‘teaching’) task of these interviews aimed not so much at teaching the pupils the conventions of the representations but rather at refreshing their knowledge of them by giving them a chance to use them in a closed-end task.

Interestingly, the use of these abstract pictures led to difficulties for some pupils. Different substances were represented by particles of different shadings; some pupils interpreted these shadings to represent substances of different *colours*. Also quite a few pupils had difficulty identifying the changes involved in the situations correctly. On the whole, these abstract pictures did not prove to support any discussion about the mechanism of a chemical change. This observation led the project team to introduce later in time a complementary set of abstract pictures, which depicted more explicitly the mechanisms of joining and splitting of substances.

4.2.2.3 Year 10 interviews

The Year 10 interviews (two altogether with eight pupils in total) entailed looking at changes similar to the ones used in the Year 8 interviews; they were about thermal energy transfers. They took place after the pupils had completed a topic on 'Energy'.

The situations used in the interview covered a variety of changes where the system is cooling, warming, is in thermal equilibrium with its surroundings or is a steady state system. These twelve situations were:

hot bath	plates in oven	snowman on a cold day
bread in freezer	ice cream on a hot day	saucepan on a cooker
hot lava from volcano	bottle on a shelf	warm room
glass of cold water	spoons in washing-up water	the Earth in space

The 'grouping' task of these interviews included an extra task, compared with the previous interviews. After the pupils had put the situations into groups of similar changes, each in turn was asked to comment on a particular pair of situations and to describe its similarities or differences, depending on whether the pupils had put these situations in the same group or not. These four pairs of situations had been selected in advance to be examples of similar changes. This addition in the interview's design was made by the project team in an effort to provoke substantially more structured comparisons, yet still spontaneous ones, by the pupils than in the equivalent ('grouping') task of the previous interviews.

In the 'matching' task, as before, the pupils were asked to match each of these situations to one of four abstract pictures. Two of them are shown in Figure 4.3.

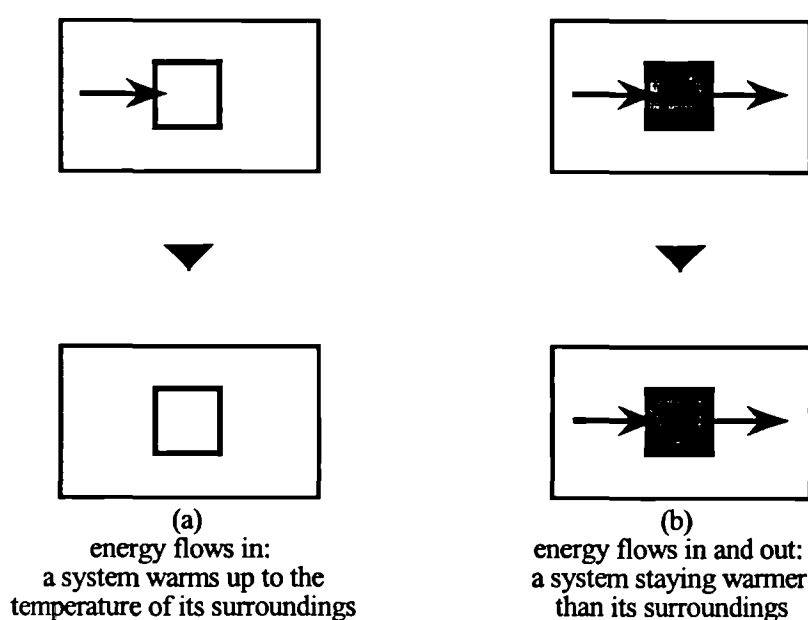


Figure 4.3 Examples of abstract pictures used in Year 10 interviews

These abstract pictures of energy transfers differed from those used in the Year 8 interviews in that these depicted each change in terms of two instances (a ‘Before’ and an ‘After’), instead of one (see Figure 4.1). Moreover, unlike in the Year 8 interviews, these kinds of pictures were now familiar to the pupils-interviewees, since they had been used quite systematically in the teaching which preceded the interviews. Consequently, the second (‘teaching’) task in the Year 10 interviews had the role of reminding the conventions of the pictures.

This experience that the pupils had with using the abstract pictures may explain why unlike the Year 8 pupils, they *were* able to use abstract pictures to support comparisons between different situations, when asked to at the end of the ‘matching’ task. They managed to make explicit use of the ideas represented by the abstract pictures and identified relevant similarities and differences which they had not identified in their initial ‘grouping’ task. Their performance in the other tasks was not dissimilar to the Year 8 pupils.

4.3 Conclusions of the first phase of the research

As already explained this first phase of the research had an exploratory character and was concerned with the development of the structure and method of the interview tool to be used in the main study. The conclusions from it that informed the design of this tool arose both from the analyses of the interviews carried out by the project and myself and from the actual experience I had of conducting some of these interviews. These conclusions were:

- The ‘grouping task’ was on the whole successful. The pupils worked constructively as a team to put the changes presented to them into groups of similar changes. They seemed quite familiar with this kind of activity and this facilitated their introduction to the interview and encouraged them to voice their spontaneous comparisons of changes without much hesitation.

The addition of a less open-ended activity to this task, similar to the one included in the Year 10 interviews, had the advantage of eliciting both more structured and more interesting data, though less spontaneous. There are two reasons for this. Firstly, this task induced comparisons between *two* situations rather than among a group of them and therefore elicited more explicit data about what features of the changes children paid attention to in making these comparisons. Secondly, by design the task evoked comparisons of situations, which had been pre-selected for their *relevance* to the ideas that interested the project.

- The ‘matching’ task, as expected, produced rich and interesting data. Prompted by the pictures, the pupils on the whole tended to give more extended responses than they did unaided by them (in the ‘grouping’ task). Also, what was interesting for the validity of the tool was that the making of successful matches seemed to depend both on pupils’ understanding of the abstract pictures and on their reasoning about the situations presented to them.

The use of numbered cards to make pupils commit themselves to their own choice of match worked very well. It provoked a good level of discussion, which often arose from differences in pupils’ choices of representations. It furthermore gave a game-like character to the task, which seemed to appeal to the pupils, particularly the less able ones.

The task seemed to interest and challenge the pupils, who on the whole participated with enthusiasm. However, the length of the task was a crucial factor in this. Where the pupils were presented with a greater number of situations (twelve in the Year 9 and 10 interviews compared with eight in the Year 8 ones) the pupils seemed to lose interest as the task progressed, their justifications becoming shorter and simpler.

- The findings were not conclusive concerning the last part of this task in which pupils were asked to identify similarities and differences between situations matched to the same abstract pictures. This task seemed not to produce much interesting data. There are at least two possible reasons for this. Firstly, there was never really enough time at the end of the interview to do it properly; and secondly, most pupils were too inexperienced in the use of abstract pictures to perform as was hoped.

CHAPTER 5

Design of the Main Study and Process of Analysis

5.1 Introduction

In the second phase of the research the accessibility and usefulness of the teaching approach and curriculum materials developed by the 'Energy and Change' project to pupils and to teachers were investigated more systematically and over a longer period. This chapter describes the design of the study in this phase and the process which was subsequently followed in the analysis of the data.

5.2 Main research questions

The thesis is concerned with the evaluation of the 'Energy and Change' teaching approach. As such it contains two dimensions, the pupil dimension and the teacher dimension. In other words it seeks to answer the following two main questions:

- A How accessible and useful are the teaching approach and curriculum materials developed by the 'Energy and Change' project for pupils at the beginning of secondary education?**
- B How accessible and useful are the teaching approach and curriculum materials developed by the 'Energy and Change' project for secondary science teachers?**

The thesis does not treat the two questions equally; the first question is more thoroughly investigated than the second. This was a deliberate decision I took, for two reasons. The first one was dictated by the nature of the study itself; for this study, which examines the accessibility and usefulness of an innovative approach, the question about teachers is important, but the question about pupils is more important. The priority is to establish that the novel approach works for pupils; only if this is the case does the question about whether teachers want to work with it become important. The second reason was a pragmatic one; it was informed by the needs to contain the extent, scope and duration of the thesis.

To answer the question about pupils one would need to address issues that concern the accessibility of the specific 'devices' (i.e. abstract pictures and terminology) used

by the project, as well as issues that concern the attainability of the objectives (general and specific) of the materials for pupils. In other words the main research question about pupils can be subdivided into questions about the curriculum innovation and questions about the pupils' learning progress from using the innovation. These issues could also be seen more specifically as arising from the question:

How do children's ideas about the nature and causes of processes of physical, chemical and biological change develop as a result of using the 'Energy and Change' project curriculum materials?

Aspects of this question were also investigated in the first phase of the research which, however, served mainly as a testing bed for the then newly developed abstract pictures as well as a pilot study of the tools of investigation. Only in the second phase of the research was the influence of the novel teaching approach on children's ideas about processes of change and their causes monitored more systematically and over a longer period.

The teacher dimension was also for the first time investigated in this second phase. The relevant main research question can, as before, be subdivided into questions about the approach, questions about the merit of the materials for teaching, as well as about their merit for teachers' personal development.

The main research questions break down as follows:

A How accessible and useful are the teaching approach and curriculum materials developed by the 'Energy and Change' project to pupils at the beginning of secondary education?

A1 About the curriculum innovation

- Is the language used by the project accessible to pupils at the beginning of secondary education?
- How do pupils manage to make sense of and use the abstract pictures?

A2 About pupils' learning when using the innovation

How do children's ideas about the nature and causes of processes of physical, chemical and biological change develop as a result of using the 'Energy and Change' project curriculum materials?

- Do pupils using the materials start to appreciate that change is caused by *differences*?

- Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these?

B How accessible and useful are the teaching approach and curriculum materials developed by the ‘Energy and Change’ project to secondary science teachers?

B1 About the curriculum innovation

- Do teachers see the materials as raising fundamental scientific issues?
- What do teachers think of the means the project chose to realise its objectives, i.e. the activities, the vocabulary used and the abstract pictures?

B2 About teaching the innovation

- Do the materials help teachers teach about energy and change?
- Could teachers find good places for the activities in the existing schemes of work?

B3 About teachers’ learning when using the innovation

- Do the materials satisfy teachers intellectually, that is do they offer a challenge for their own ideas, and help them to sort them out better?

5.3 Organisation of field work

The field work took place during the academic year 1993-94, in a mixed London comprehensive school which had agreed to integrate the teaching material produced by the ‘Energy and change’ project in their Key Stage 3 science curriculum.

The characteristics of the school can best be described by quoting from its OFSTED inspection report (OFSTED, 1996):

“The school is [...] in an inner city area which has many features of inner city deprivation. [...] It serves a diverse multi-cultural community. The school recruits from the full ability range with a predominance of lower ability students. [...] Many students are at the early stages of learning English; six out of seven students receive additional support in this respect. There is a high turnover as new students join the school and others move to more settled circumstances outside the area.” (p8)

In this school the lessons take place in mixed-ability classes, although given the low ability intake of the school, *“overall attainment is well below that expected nationally” (ibid, p13)*. More relevantly for the purposes of this study, the same

report states that attainment in science ranges from good to below average, and particularly in KS3 is below the national standard.

This choice of school was not fully in my control; it had rather been suggested by the project's team, which had been piloting some of the materials there since before this phase of the research began. Given the fact that the curriculum intervention planned would extend over a period of eight months, it was not envisaged as likely that there would be many schools which would agree to it, and thus the decision was taken to base the evaluation of the project's materials in this school. The characteristics of the school may not have been ideal for such an endeavour, but on the other hand were thought of as appropriate since the novel approach is meant to be used by and with pupils of all abilities and learning needs.

In this school, I worked with one Year 7 and one Year 8 class, that is, with 11-13 year-old pupils, over a period of eight months. More particularly, I worked with 25 pupils in Year 7 for almost eight months and with 24 pupils in Year 8 for almost six months. Because of the high turnover of pupils in the school and of their comparatively low attendance, the number of pupils in each class fluctuated a lot, around an average of 20 pupils in the class on any given day.

The choice of the age group of children to work with was informed by many considerations. One of the original features of the project is that it suggests a language to introduce the thermodynamic principles that govern change that can be accessible to pupils even at the beginning of secondary education, so it was important to work with pupils of this age. Moreover, it was thought that the way of looking at processes of change that was introduced in the curriculum materials developed by the project would be more easily adopted the younger the pupils were exposed to it. There was also a practical reason for choosing these classes, that of the availability of the materials to be used in the classroom; at that point in time materials for older pupils were not available.

5.4 Situating the research

The science curriculum in the school in which I did my research is organised into a number of topics; it was arranged that the project's materials would be used for the teaching of three topics in each class. For Year 7 the three topics were 'Water', 'Air / Materials' and 'Life', while for Year 8 these were 'Substances', 'Energy' and 'Food and Fuels'. The choice of the topics was not under my control; they were chosen by the project both because they were important to their work and because they were seen as spanning all the traditional areas of science - Physics, Chemistry, and Biology. Processes of dissolving, mixing, crystallisation, diffusion, but also changes

of state, energy flows and chemical changes were examined in the classroom using the materials and activities produced by the project.

These materials and class activities for Year 7 invite pupils to pay attention to differences in concentration and to identify matter ‘spreading out’ and ‘bunching together’, mixing and ‘unmixing’; to pay attention to existing differences in temperature and to identify their disappearance, and finally to processes that happen easily but are more difficult to reverse. In Year 8 the project’s materials and class activities introduce pupils to the particle nature of matter and to changes to it; they invite them to pay attention to changes where the particles are ‘joining’ or ‘splitting’ and to differentiate these from changes where particles are ‘mixing’ or ‘un-mixing’. They also require the pupils to look for temperature differences and to identify energy flows due to temperature differences. Energy flows should also be seen as flowing from stores of concentrated energy such as fuel-oxygen systems. These stores are presented as stretched chemical springs; 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 don’t; 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 7 the topic of ‘Life’ was introduced after those of ‘Water’ and ‘Air/Materials’ as the study of living processes requires some understanding of temperature differences and concentration differences, introduced in the first two topics. Similarly, in Year 8 the topic ‘Food and Fuels’ was introduced after those of ‘Substances’ and ‘Energy’ as the discussion of burning food and fuels requires some understanding of chemical change and energy flows, introduced in the first two topics.

Finally, the choice of activities for each topic was informed by both what the school already included as work for this topic in its schemes of work and what was desirable to be done based on the project’s approach. The need to match the progression of the project’s activities with the way the school already taught the topics resulted in some activities not really falling in the ideal or most logical order. This point will become clearer in Chapters 6 and 8 where a more detailed discussion of the activities and their use in the Year 7 and 8 classes respectively takes place.

5.5 Developing the research questions

Examples are given below (Tables 5.1 - 5.2) of the way the previously mentioned research questions were used to generate further specific questions, which could more easily and directly be addressed from the data.

RESEARCH QUESTIONS - PUPIL DIMENSION	
A	How accessible and useful are the teaching approach and curriculum materials developed by the ‘Energy and Change’ project to pupils at the beginning of secondary education?
A1	<u>About The Curriculum Innovation</u>
A1.1	<p>Is the language used by the project accessible to pupils at the beginning of secondary education? For example:</p> <ul style="list-style-type: none"> <i>How did the pupils manage to use the language developed by the project (to describe the abstract pictures) in their explanations of physical, chemical and biological change?</i> <i>Did the pupils show any progress in using it with time?</i>
A1.2	<p>How do pupils manage to make sense of and use the abstract pictures? For example:</p> <ul style="list-style-type: none"> <i>Did the pupils have any problems interpreting the abstract pictures?</i> <i>Did the pupils show any progress in using them with time?</i> <i>Did the pupils have any problems matching real world situations to the abstract pictures?</i> <i>Did matching real world situations to the abstract pictures help the pupils pay attention to the more abstract-generalised features of the changes?</i>
A2	<u>About Pupils’ Learning When Using the Innovation</u>
	<p>How do children’s ideas about the nature and causes of processes of physical, chemical and biological change develop as a result of using the ‘Energy and Change’ project curriculum materials? <u>Questions related to the general objectives of the teaching approach</u></p>
A2.1	<p>Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? For example:</p> <ul style="list-style-type: none"> <i>Did the pupils focus more on ‘differences’, especially of concentration and temperature, when they reasoned about change?</i>
A2.2	<p>Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? For example:</p> <ul style="list-style-type: none"> <i>What features of the situations did the children pay attention to in seeing similarities/differences?</i> <i>Did the pupils shift from seeing processes of physical and chemical change as all very different from one another, to seeing basic similarities between them?</i> <i>Did the abstract pictures help the pupils to see similarities between apparently different situations by considering the abstract-generalised features of the processes involved?</i>

<u>Questions related to the specific objectives of the project's curriculum materials for Year 7 and 8</u>	
A2.3	Do Year 7 and 8 pupils show any progress in respect to the specific objectives of the project's curriculum materials for these years?
	<u>Year 7</u>
	<ul style="list-style-type: none"> • <i>Did the pupils pay attention to differences in concentration and identify matter 'spreading out' and 'bunching together', 'mixing' and 'un-mixing'?</i> • <i>Did the pupils pay attention to existing differences in temperature and identify their disappearance?</i> • <i>Did the pupils identify processes that happen easily, but are more difficult to reverse?</i>
	<u>Year 8</u>
	<ul style="list-style-type: none"> • <i>Did the pupils differentiate between changes where the particles are 'joining' or 'splitting' and changes where the particles are 'mixing' or 'un-mixing'?</i> • <i>Did the pupils look for temperature differences and identify energy flows due to these temperature differences?</i> • <i>Did the pupils identify energy as flowing from stores of concentrated energy such as fuel-oxygen systems?</i> • <i>Did the pupils consider that some changes 'just happen', while some do not, and that for a non-spontaneous change to happen there has to be a spontaneous one to drive it?</i>

Table 5.1 Research questions - Pupil Dimension

RESEARCH QUESTIONS - TEACHER DIMENSION	
B	How accessible and useful are the teaching approach and curriculum materials developed by the 'Energy and Change' project to secondary science teachers?
B1	<u>About the Curriculum Innovation</u>
B1.1	Do teachers see the materials as raising fundamental scientific issues?
B1.2	What do teachers think of the means of the project chose to realise its objectives, i.e. the activities, the vocabulary used and the abstract pictures?
	For example:
	<ul style="list-style-type: none"> • <i>How accessible and relevant did the teachers find the curriculum materials for the pupils?</i>
B2	<u>About Teaching the Innovation</u>
B2.1	Do the materials help teachers teach about energy and change?
	For example:
	<ul style="list-style-type: none"> • <i>Did the materials help the teachers find simple ways of talking with pupils about energy and change?</i> • <i>How did the teachers cope with using the materials?</i> • <i>How did the teachers see the activities suggested in the materials relate to the practical work the pupils are meant to do in the classroom?</i>
B2.2	Could teachers find good places for the activities in the existing schemes of work?
B3	<u>About Teachers' Learning When Using the Innovation</u>
B3.1	Do the materials satisfy teachers intellectually, that is do they offer a challenge for their own ideas, and help them to sort them out better?

Table 5.2 Research questions - Teacher Dimension

5.6 Data collected and rationale for collecting it

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

- interviews carried out with the pupils;
- observational records of the science lessons attended for both classes;
- copies of all the pupils' written assignments and tests;
- copies of the teachers' completed evaluation forms for each of the project's activities they used in the classroom;
- notes from teachers' meetings with designer of project's materials;
- interviews with all the science teachers of the school;
- questionnaires administered to teachers who had attended one-day INSET sessions about the project; and
- interview with Richard Boohan, co-director of the 'Energy and Change' project.

Having established that the interviews used in the first phase of my research were a successful research tool for children's ideas about the nature and causes of processes of change, and since they had a structure that reflected the teaching approach developed by the project, I decided to use them as my main research tool for assessing the effects of the teaching approach on pupils' ideas about change. By controlling their design I was able to address specific research questions and obtain detailed information about them from all the pupils of each class. On the other hand, information was also required about the kind of experiences the children were exposed to in the classroom and about how the project's materials were actually used by the pupils and their teachers. It was decided that I would gather this information by keeping observation records of almost all the science lessons in which the project materials were being used in both classes, by keeping copies of the pupils' written assignments and tests and by keeping copies of the teachers' completed evaluation forms for each one of the project's activities used. This information was later used to build the profiles of six pupils in each class and their teachers.

Furthermore, the role of the teachers in the teaching process as well as their professional experience was not ignored. Interviews were conducted with all the science teachers of the school and questionnaires were administered to teachers who had attended one-day INSET sessions about the project. In these the teachers had the opportunity to express their views about the teaching approach and materials.

Finally, throughout the implementation of the intervention, but also after, during the subsequent analysis of the data, I had many informal discussions with both directors

of the project as well as a formal interview with Richard Boohan (co-director of the project and designer of the curriculum materials), about the development of the innovation, its objectives, and its limitations.

5.6.1 Interviews with pupils

The design of the interviews was only slightly modified compared with phase one, in the attempt to make the interviews yield somewhat more structured data, with the rationale behind the design staying the same. However, the interviews used in the second phase of the research had a different emphasis from those used in the first phase. Whereas in the first phase, the interviews aimed at detecting the effects of the use of abstract pictures in the course of a single interview, in my main study they aimed at detecting the effects of a systematic use of these pictures in the classroom, in the context of the three learning sequences I referred to before. In other words, the role of the second task (the so called ‘teaching’ task) in the first phase interviews, was in the second phase played by the teaching that took place between the interviews.

I conducted interviews with all the pupils of each class in groups of four (on three occasions the groups consisted of five pupils). The design of these interviews is summarised in Figure 5.1. The first interviews were conducted before any teaching of the project materials took place, and thus did not include use of abstract pictures. Subsequent interviews were carried out after each of the three learning sequences I referred to before, with one to three-month intervals between them. The first interviews consisted of two tasks whereas subsequent interviews consisted of three (now including abstract pictures).

In the first (‘grouping’) task of all interviews pupils were presented with a number of situations schematically drawn on cards with captions describing them. Twelve situations were used in the first set of interviews (A interviews) and eight for the subsequent three (B, C and D interviews). This was because the A interviews, unlike the rest, were conducted before any teaching using the project materials took place, and so it was important that pupils reasoned about a number of different changes in order to establish their starting point.

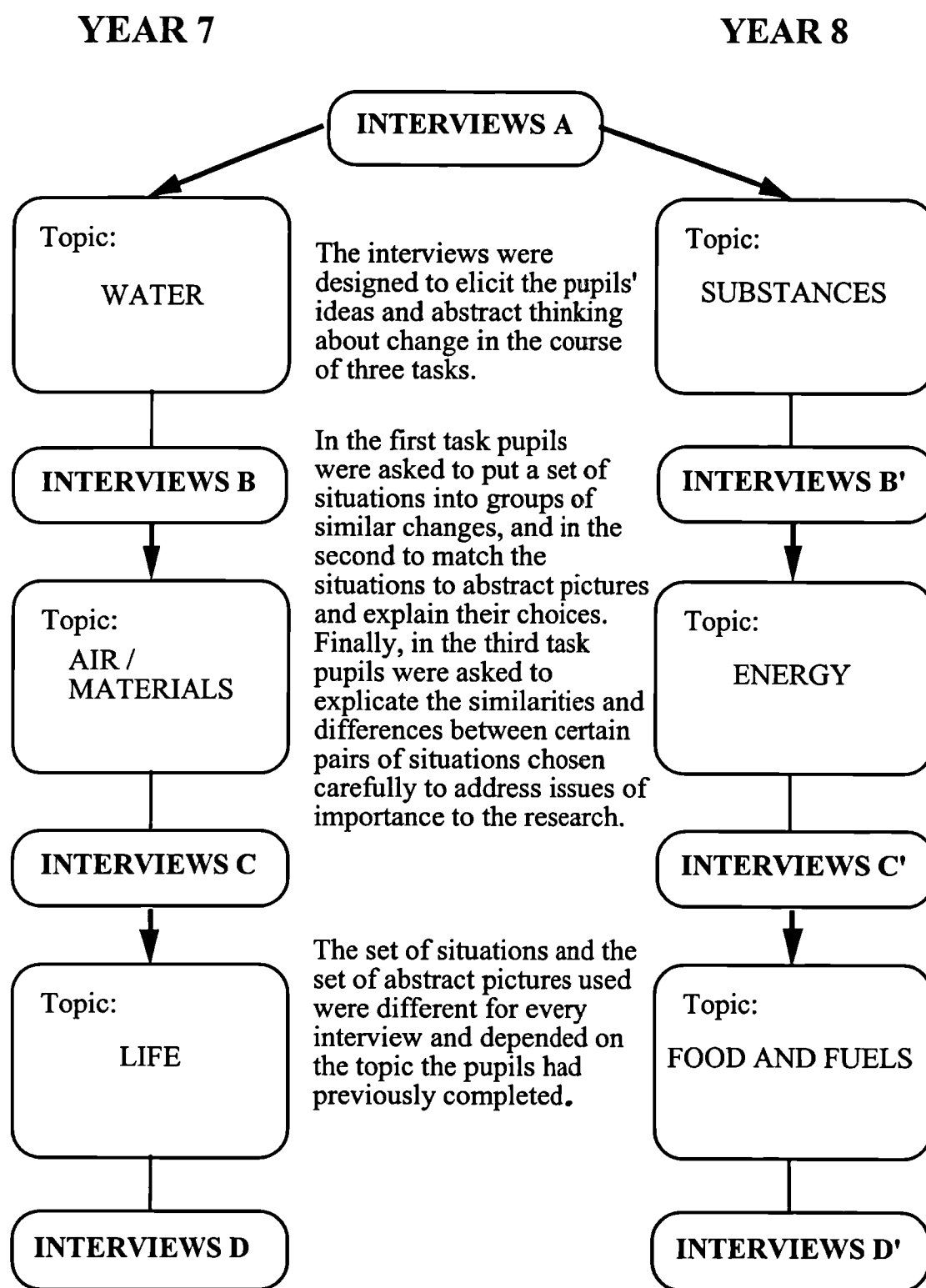


Figure 5.1 Design of pupils' interviews and relations to taught topics and their timing

There were also some practical considerations for deciding to use eight situations for the B, C and D interviews (see also conclusions of the first phase of the research - section 4.3). One was that the interview should not last more than 30 minutes - an aim that was in practice rarely met - and a second that the groups to be interviewed

consisted of four pupils: having eight situations would give each pupil two opportunities to match a situation to an abstract picture in the second ('matching') task. The choice of situations for every set of interviews depended partly on the topic the pupils had previously completed; however, attention was also paid to including situations the pupils had not met in their lessons. The situations every time were intended to cover systematically a variety of physical changes - matter-only (M), energy-only (E), and matter-energy (PH) changes - as well as chemical (CH) and biological (L) changes. Finally, some of the situations were used in more than one interview to provide some cross-checking. Table 5.3 contains a list of all these situations, and shows which of them were used in which interviews. In appendix 5.1 one can find these situations in the form they were presented to pupils, that is as schematic realistic pictures with a caption.

	Situations used in interviews with pupils	Y7 A	Y7 B	Y7 C	Y7 D	Y8 A	Y8 B	Y8 C	Y8 D
M1	metal foil being crumpled up						•		
M2	a car windscreen being shattered	•				•			
M3	making soup out of powder soup and water	•				•			
M4	cleaning a paint brush in water		•				•		
M5	purifying water		•				•		
M6	smoke filling the air over a city			•				•	
E1	a hot bath cools down	•			•	•			•
E2	an electric iron cools down after being switched off		•					•	
E3	a cold drink left out in the sun	•		•		•			
E4	warming your hands near the fire / by the radiator		•	•				•	
E5	pulling a catapult to get ready to fire a stone								•
PH1	scent or after-shave evaporating from the skin	•				•			
PH2	getting salt by evaporating salt solution			•					
PH3	fruit drying in the sun	•				•			
PH4	ice forming on a pond	•			•	•			•
PH5	hot lava from a volcano turns solid	•				•			
PH6	crystals forming in copper sulphate solution as it cools		•						

	Situations used in pupils interviews (cont.)	Y7 A	Y7 B	Y7 C	Y7 D	Y8 A	Y8 B	Y8 C	Y8 D
PH7	the windows of the car misting up on a very cold day		•						
PH8	water vapour forms clouds / and it rains			•				•	
PH9	a snowman melting						•		
PH10	melting wax			•				•	
CH1	acid rain eroding a stone statue	•			•	•			•
CH2	wood burning	•		•	•	•			•
CH3	an explosion		•					•	
CH4	a car rusting						•		
CH5	putting Alka Seltzer in water						•		
CH6	extracting copper by electroly- sing copper sulphate solution						•		
CH7	charging a car battery								•
L1	a plant growing	•			•	•			•
L2	your hair growing		•						
L3	a baby's bones growing						•		
L4	your body making extra fat				•			•	
L5	digesting food	•				•			
L6	running and using up food				•				•
L7	sweating to stay cool				•				
L8	your body staying warm on a cold day			•				•	

Table 5.3 *Situations used in interviews with Year 7 and 8 pupils*

For the ‘grouping’ (first) task of the interview the cards with the situations were spread out on a poster paper so that they formed a circle; for each situation in turn, starting with the one at the top of the circle and working clockwise, the pupils were asked to consider the change involved and to choose among the rest the one they thought was most similar. I shall call the situation from which they started the ‘situation of prime focus’. After they had agreed on a match and had explained their choice an arrow would be drawn from the situation in focus to its match. The task lasted until most of the situations were somehow considered, that is they had either been situations of prime focus or had been chosen as matches to such situations. The situation of prime focus was thought to work as a trigger for the choice of its match, this is why the pupils were guided to consider first those situations they had met and discussed in their science lessons using the project’s materials. This approach of examining the situations in a more or less set order was not followed in the A (first) set of interviews, where the pupils, although still guided to focus on one situation at a time, most often themselves picked the situation, or the pair of situations they wanted

to talk about, with the aim still being to cover all the situations on the poster paper if possible.

This task was expected to provide information about what features of the changes children pay attention to spontaneously in seeing similarities, as well as information about how children think of particular changes. Moreover, a comparative analysis of the children's performance in this task between the first and last sets of interviews could provide us with data about the long-term effects of the teaching approach (see, for example, sections 7.2 and 9.2).

In the second ('matching') task of the A (first) interviews the pupils were presented with four pairs of situations, chosen by me from the twelve situations of the 'grouping' (first) task, and with twenty phrases written on separate cards. These phrases were intended to describe what is happening in a change and were chosen so that they reflected the ideas addressed by the project; in other words, they referred to changes in matter, changes in energy and to the spontaneity and reversibility of a change (see Table 5.4). For each pair of situations laid down on a poster paper in turn each pupil was asked to choose one phrase (out of the twenty) which s/he thought was true for both changes (similarity), one which s/he thought was true for only one of the changes (difference) and, if time allowed, one which s/he thought was completely untrue for both changes (similarity). The pupils were also asked to talk about the reasons behind their choices as well as for any disagreement. The phrases were actually placed on the poster paper depending on whether they were thought to be true for both or for one of the changes, either between the situations or under each of them. This task was slightly varied in the Year 8 interviews. In these each pupil was given five phrases selected randomly out of the twenty; out of them s/he had to find one that s/he thought was true for both or one of the changes. The group had to reach a consensus about each of the choices made before the phrase was placed on the poster paper. This time for each pair of situations I had pre-selected a set of (maximum) six phrases as interesting to discuss. If some of these were not already discussed by the pupils, I would introduce them and ask the pupils to match them to one or to both changes.

The interest here was on how the pupils managed to apply specific ideas in their explanations for physical, chemical and biological change when they were prompted to do so by given phrases.

In the 'matching' task of the (later) B, C and D interviews the pupils were asked to match the situations of the 'grouping' task to abstract pictures and explain their choices. The abstract pictures used in any one of these interviews were chosen to relate to the ones the pupils had met in the preceding learning sequence, and thus

depicted a subset of the ideas addressed by the equivalent phrases in the first interview (see Table 5.4). This ‘matching’ task was now expected to provide information about 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 (see, for example, sections 7.3 and 9.3). Did matching real world situations to abstract pictorial representations help draw children’s attention to the more generalised features of the changes? Did the pupils have any problem interpreting and using the abstract pictures?

Finally, in the third (‘comparing’) task, after the pupils had matched all the situations, I would ask them to explicate the similarities and differences between certain pairs of situations chosen carefully to address issues of importance to the research. For each pair of situations I had also selected two or three phrases (out of the twenty used in the A interviews) which contained important ideas not addressed by the abstract pictures; the pupils were asked to say whether these described appropriately what was happening in the changes. This third task would show how well children managed comparisons of different physical and chemical changes using the abstract pictorial representations, and the level of generalisation which they achieved. It would also show whether and how the pupils made use of the language developed by the project when they identified similarities and differences between different changes.

Phrases and abstract pictures used in pupils interviews			Y7 A	Y7 B	Y7 C	Y7 D	Y8 A	Y8 B	Y8 C	Y8 D
P H R A S E S	M A T E R	something spreads out	•			•	•			
		something bunches together	•				•			
		something is mixing	•				•			
		something is unmixing	•				•			
		something becomes solid	•				•			
		something becomes liquid	•				•			
		something becomes gas	•				•			
		it makes a new substance	•		•	•	•		•	
		a substance changes	•				•			
		substances stay the same	•				•			
		something disappears or gets used up	•				•			
	EN	something gets warmer	•				•			
	ER	something gets cooler	•				•			
	GY	temperature evens out	•				•			

Phrases and abstract pictures used in pupils interviews (cont.)			Y7 A	Y7 B	Y7 C	Y7 D	Y8 A	Y8 B	Y8 C	Y8 D
P H R A	EN	temperature stays the same	•				•			
	ER	energy spreads out	•	•			•			
	GY	energy becomes concentrated in something	•	•			•			
S E S	SP	it happens by itself	•	•	•		•	•		
	ON	someone makes it happen	•	•			•			
	TA N.	it is easy to reverse the change	•	•			•	•	•	
A B S T R A C T P I C T U R E S	M A T T E R	spreading out		•	•	•			•	
		bunching together		•	•	•			•	
		mixing		•				•		
		unmixing		•				•		
		joining						•		
		splitting						•		
		re-arranging						•		
		no change		•	•	•		•	•	
		disappearing		•		•				
		appearing from nothing		•		•				
C T U R E S	E N E R G Y	keeping a balance				•				
		difference in temperature disappears			•					
		difference in temperature appears			•					
		no change			•					
		difference in temperature is maintained			•					
		energy spreads out							•	
		energy becomes concentrated							•	
		energy escapes I								•
		energy is stored I								•
		energy escapes II								•
AB ST	SP ON T.	energy is stored II								•
		no energy change							•	•
		energy stays concentrated							•	
		it ‘just happens’ by itself								•
		it needs something to make it happen								•

Table 5.4 Phrases and abstract pictures used in Year 7 and 8 interviews

Table 5.4 above shows which phrases and abstract pictures were used in each interview. Moreover, in appendices 5.2-5.9 one can find the schedules of the interviews and can see the abstract pictures that were used in them. Finally, appendix 5.10 gives an idea of the considerations that underlay the design of any one interview, by recounting in detail the rationale behind the second (B) of the Year 7 interviews.

5.6.2 Classroom observations

For all the reasons mentioned above, it was decided that I would keep detailed observational notes on each lesson attended (sixty four lessons in total - forty one from Year 7 and twenty three from Year 8 -, equivalent to approximately 90 hours of observation). I took care to note down as much as possible from each lesson I observed, including quotations of the actual teacher's and students' talk. In my notes I tried to include information about how the teacher presented the ideas and the activities of the project and how the children responded to them.

In addition I decided to follow a smaller number of pupils in more detail. So, for each class, with the aid of the science teacher of the class, I selected three pairs of pupils in the better half of the ability range (i.e. representative of pupils of around average attainment nationally, bearing in mind the low ability intake of the school) to follow more closely their progress in the course of the year; in my records of each lesson I tried to say something about how they performed in the projects' activities, what they thought they were about, how easy or difficult they found them etc.. In order to render these observations easier, the pupils were grouped in pairs; each pair was seated together, worked together in group-work activities (e.g. investigations), and participated together in the group interviews I conducted.

5.6.3 Pupils' written work

For the same reasons, but also for the purpose of establishing the ability of each pupil, I also kept copies of all the written assignments and tests the pupils did as part of the three science topics I monitored.

Data from both these sources were intended to help me address the question of whether and how the experiences that children had in the classroom influenced the development and expression of their ideas about processes of change and their causes. The work accomplished by the six selected pupils in each class based on the lesson records and on their written assignments and tests was used as the basis for a number of case studies (see sections 6.4 and 8.4).

An example of a classroom observation, the corresponding teaching material and teaching notes, and examples of two pupils' relevant written work are shown in Appendices 5.11-5.13.

5.6.4 Interviews with teachers

The classroom observations were also useful for providing information about how the teachers used the materials in the classrooms. In addition, it was important to find out how accessible and useful these teaching materials had been to them, what problems, if any, the materials had presented them, how easy or difficult their integration in schemes of work had been, etc.. To that end, I carried out a one-hour interview with each of the two teachers who had used the materials systematically in their teaching, but also with the other three science teachers in the school as they had also had a chance to look at the project's work at two in-service-training sessions the project had organised for them. To them I presented a total of fifteen statements (six negative and nine positive) about the project and asked them to comment on each. I then asked them to tell me what they saw as the main things the project is trying to achieve, and for three of the pupils' activities to specify whether and how they saw these helping in the long run to build up children's ideas. The interviewees had had previous experience with these three activities, doing them and talking about them in the second of the INSET sessions organised by the project. The interview schedule used in the teachers' interviews can be seen in appendix 5.14.

Finally, these same fifteen statements were also given, in questionnaire form (seen in appendix 5.15), to forty-two science teachers who had attended one-day INSET sessions about the approach. These teachers had to state on the form whether they strongly agreed, agreed, disagreed or strongly disagreed with the statements by ticking the appropriate boxes. The questionnaire was administered by the project to test teachers' immediate reactions. It was recognised at that time that some of the statements were very complicated and, while appropriate for use as triggers for discussion in an interview, did not lend themselves ideally for use in a closed questionnaire. Nevertheless, it was decided that there were merits in using the statements unchanged, as they had appeared in the interviews, one being that I could then use the answers in the questionnaires in conjunction with those of the interviews in a discussion of teachers' reactions.

The two teachers I worked with were asked by the project to fill in evaluation forms for each of the project's activities they used in the classroom. I kept copies of these. Moreover, I kept notes from the meetings they held with the designer of the project's activities, Richard Boohan, at regular intervals during the intervention period. At this

time the project's materials were in the process of development and the primary purpose of the meetings was to acquaint the teachers with the newly written materials as well as to give the authors of the materials an immediate feedback to the first version of the materials. However they also served the additional purpose of allowing me to monitor the teachers' initial reaction to the new materials as they were being developed. They thus served as a valuable source of data for this evaluation - allowing a comparison to be made between the views of the teachers when they first met the materials and after they had used them. It should be stressed that these meetings were around 15 minutes each and generally took place just before the teachers were due to start teaching each topic.

5.6.5 Interview with the project's co-director

It was also thought important to hear from the creators of the novel approach about their perception of its strengths and weaknesses. So apart from the many informal discussions I had with them throughout this study, I conducted a one-hour interview with Richard Boohan, the project's co-director and designer of the curriculum materials. I asked him to talk to me about the origin of the ideas underlying the new approach and about the considerations that went into their transformation into curriculum materials. I also asked him to define for me the general aims of the project, as well as the particular objectives of the interventions in Years 7 and 8. What would be desirable outcomes of these interventions in his view? Finally, I queried him about the limitations of the materials and about how these materials could be improved and/or their scope could be extended.

5.7 Process of analysis

The data collected were analysed from different perspectives in an attempt to answer as comprehensively as possible the research questions previously defined. Table 5.5 shows the different kinds of outputs that ensued from these analyses and provides information about the sources of data used and the research questions addressed in them. Next to each research question there is also a reference to the section of the thesis which contains the corresponding conclusions. In addition, the subsections which follow recount in detail the process of analysis which was followed in each case.

Kinds of Outputs	Sources of Data used	Research Questions addressed
Discussion of project's activities used in the intervention	<ul style="list-style-type: none"> • interview with Richard Boohan • observational records of the science lessons attended • project's activities and corresponding teaching notes 	<p>Note: This discussion provided the essential context for answering of research questions</p>
Teacher case study	<ul style="list-style-type: none"> • observational records of the science lessons attended • teacher's completed evaluation forms for the project's activities used • notes from teacher's meetings with Richard Boohan • interview with teacher 	<p>B1.1 Do teachers see the materials as raising fundamental scientific issues? (section 11.3.1)</p> <p>B1.2 What do teachers think of the means of the project chose to realise its objectives, i.e. the activities, the vocabulary used and the abstract pictures? (section 11.3.2)</p> <p>B2.1 Do the materials help teachers teach about energy and change? (section 11.3.3)</p>
Pupil case studies	<ul style="list-style-type: none"> • observational records of the science lessons attended • records of pupils' written assignments and tests 	<p>A1.1 Is the language used by the project accessible to pupils at the beginning of secondary education? (section 11.2.1)</p> <p>A1.2 How do pupils manage to make sense of and use the abstract pictures? (section 11.2.2)</p> <p>A2.1 Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? (section 11.2.3)</p> <p>A2.2 Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? (section 11.2.4)</p> <p>A2.3 Do Year 7 and 8 pupils show any progress in respect to the specific objectives of the project's curriculum materials for these years? (sections 7.6 and 9.5)</p>

Kinds of Outputs	Sources of Data used	Research Questions addressed
‘Grouping’ task: Comparison of all first (A) and last (D) interviews	<ul style="list-style-type: none"> task 1 of first (A) set of interviews task 1 of last (D) set of interviews 	<p>A2.1 Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? (section 11.2.3)</p> <p>A2.2 Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? (section 11.2.4)</p>
‘Matching’ and ‘comparing’ tasks: Comparison across each group’s interviews	<ul style="list-style-type: none"> tasks 2 and 3 of all four interviews for each group of pupils (three groups in total) 	<p>A1.1 Is the language used by the project accessible to pupils at the beginning of secondary education? (section 11.2.1)</p> <p>A1.2 How do pupils manage to make sense of and use the abstract pictures? (section 11.2.2)</p> <p>A2.1 Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? (section 11.2.3)</p> <p>A2.2 Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? (section 11.2.4)</p> <p>A2.3 Do Year 7 and 8 pupils show any progress in respect to the specific objectives of the project’s curriculum materials for these years? (sections 7.6 and 9.5)</p>
Situations common to more than one interview: Comparison of explanations for each group (reported in the appendix)	<ul style="list-style-type: none"> tasks 2 and 3 of all four interviews for each group of pupils (three groups in total) 	<p>A1.1 Is the language used by the project accessible to pupils at the beginning of secondary education? (section 11.2.1)</p> <p>A2.1 Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? (section 11.2.3)</p> <p>A2.3 Do Year 7 and 8 pupils show any progress in respect to the specific objectives of the project’s curriculum materials for these years? (sections 7.6 and 9.5)</p>

Kinds of Outputs	Sources of Data used	Research Questions addressed
‘Grouping’ task: Comparison of all Year 7 last (D) and Year 8 first (A) interviews	<ul style="list-style-type: none"> task 1 of last (D) set of Year 7 interviews task 1 of first (A) set of Year 8 interviews 	<p>A2.1 Do pupils using the materials start to appreciate that change is caused by <i>differences</i>? (section 11.2.3)</p> <p>A2.2 Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? (section 11.2.4)</p>
Teachers’ reactions	<ul style="list-style-type: none"> questionnaires administered to 42 teachers who had attended one-day INSET sessions about the project interviews with all five science teachers of the school 	<p>B1.1 Do teachers see the materials as raising fundamental scientific issues? (section 11.3.1)</p> <p>B1.2 What do teachers think of the means of the project chose to realise its objectives, i.e. the activities, the vocabulary used and the abstract pictures? (section 11.3.2)</p> <p>B2.1 Do the materials help teachers teach about energy and change? (section 11.3.3)</p> <p>B2.2 Could teachers find good places for the activities in the existing schemes of work? (section 11.3.4)</p> <p>B3.1 Do the materials satisfy teachers intellectually, that is do they offer a challenge for their own ideas, and help them to sort them out better? (section 11.3.5)</p>

Table 5.5 *Kinds of analysis outputs and research questions addressed*

5.7.1 Discussion of project’s activities used in the intervention

Drawing on the interview I had with the designer of the intervention, I defined what the ideal progression of the project’s activities would have been for each Year.

I then attempted to give a detailed account of the actual experiences the pupils had in the classroom using the project’s activities. In these accounts (see sections 6.2 and 8.2) I made a point of mentioning the cases where I thought that the suggestions given in the teaching notes for the activity had not been realised.

5.7.2 Teacher case study

I extracted from the lesson observation records the passages that referred to the teacher and I collated them. Then, drawing mainly on them and on the teacher's interview, but also, when appropriate, on the other relevant sources of data, I tried to address the identified research questions (see outputs in sections 6.3 and 8.3). These latter for the purpose of the case study were broken down to the following more specific questions:

- Did the teacher grasp the general long-term aim of the project?
- What did she see as the main things the project is trying to achieve?
- How did she feel about the use of the project's materials in her classroom and my presence there?
- Did she have an overview of the objectives of these materials?
- Did she find the curriculum materials accessible and relevant for her pupils?
- Did she fully explore the opportunities offered by the materials?
- Did she adhere to the teaching notes of the activities?
- How did she cope in the classroom with the project's suggested language and the ideas expressed by it?
- How did she cope with the project's abstract pictures? Did she make spontaneous use of them in her teaching?
- What did she think of these project 'devices'?
- Did she encourage pupils to identify similarities and differences between different changes?

5.7.3 Pupil case studies

As in the teacher case study, I first extracted from the classroom observations the passages that referred to the six pupils selected from each year group to be studied in more detail. I then went through their written assignments and tests examining the answers they gave in the project's activities and looking for signs of progress or lack of it, with reference to the specific objectives of the materials for each year group.

Drawing on both these data, I went on to answer the following list of questions, which I saw as emanating from the identified research questions:

- Did the pupil focus more on differences, especially of concentration and temperature, when s/he reasoned about change? Did s/he recognise that these differences tend to disappear?

- How did the pupil manage to use the terms suggested in the materials? Did s/he show any progress in using them with time?
- Did the pupil have any difficulty interpreting the abstract pictures? Did s/he show any progress in using them with time? What kind of pictures did s/he draw spontaneously to depict a change?
- Did the pupil manage to identify basic similarities between apparently different situations? What features of the situations did the pupil pay attention to when s/he did this? Did the abstract pictures help him/her consider the abstract-generalised features of the processes involved as the basis of this identification?

One can see the outputs of this analysis for Year 7 and Year 8 in sections 6.4 and 8.4 respectively.

5.7.4 'Grouping' task: Comparison of all first (A) and last (D) interviews

5.7.4.1 Rationale of the analysis

As mentioned before, the 'grouping' task of the interviews was expected to provide information about what features of the changes pupils pay attention to spontaneously in seeing similarities, as well as information about how children think of particular changes. A comparative analysis of the pupils' performance across the sets of interviews could provide evidence about the long-term effects of the novel teaching approach.

A desirable outcome of this analysis from the project's point of view would be that at the end of the teaching intervention the pupils were more able to focus on the essential features of the changes and draw similarities based on these. It would also be desirable if the pupils arrived at using the ideas met in their classroom when they reasoned spontaneously about the changes - those they had already studied as well as those which were less familiar to them. However, while these effects would certainly be welcomed if detected, for one to presume to find them easily, or in quantity, would be unrealistic. One reason for this is that the period of six (in effect) months for which the teaching approach was tried out in each classroom was not enough for it to yield such effects, as it is designed to work over four years of continuous and consistent use. Another reason is that the task itself was very open-ended; while the pupils were asked to concentrate on what was happening in each of the given changes and based on that to look for similar ones, they were given no other clues as to what was considered a 'good' or a 'better' match. Furthermore, most of the situations were chosen to depict familiar everyday changes; this means that the

changes triggered a lot of everyday associations for the pupils, associations which most probably did not require a deeper understanding of the processes involved. Finally, as said before, the situations covered a variety of changes only some of which the pupils had discussed in their lessons.

These facts meant that the comparative analysis of the different sets of interviews for the ‘grouping’ (first) task would yield more subtle changes. For this reason I decided to do this comparison between the first (A) and last (D) sets of interviews instead of across successive sets (see outputs in sections 7.2 and 9.2). The idea was that if there was any difference in children’s performance of the task with time, this would be more manifest in the comparison of the first (A) with the last (D) interviews. For this purpose I used all the groups transcripts for the first and last sets of interviews (i.e. five and four respectively).

5.7.4.2 Pupils identifying similarities

Kinds of groupings

My first concern was to divide the transcripts into units of analysis. Each attempt to link two situations was thought of as a unit irrespectively of whether it ended up getting the necessary consensus from the group to become a decision. So the units could be extended discussions about a possible match with all the pupils participating; could be a single explanation offered by one pupil and readily accepted or rejected by the others; or could be a suggestion, which no pupil cared to elaborate.

Then I looked for characterisations that could describe with one word the relationships the pupils identified between the two situations they wanted to link. I ended up with five different categories:

‘Arbitrary’: The pupils would evoke an arbitrary relationship between the two situations in order to justify the match. This was often constructed by reasoning that an element of one change could be the agent of the other. For example ‘acid rain eroding a stone statue’ was found similar to ‘a car windscreen being shattered’ because:

“When the acid rain comes down the windows break. The rain falls on the glass.”

An ‘arbitrary’ justification could also be a superficial similarity called upon to satisfy the need for a match to be made and an explanation to be given. For example ‘making soup out of powder soup and water’ was found similar to ‘acid rain eroding a stone statue’ because:

“Powder is coming into the saucepan and the acid is falling from the sky.”

‘Script’: The pupils would evoke a sequential relationship between the two situations; one situation was said to be following on from the other, either in time or as a consequence. I called this type of justification ‘script’ because it was as if two changes were found similar based on the script they evoked in the minds of the pupils. For example ‘making soup out of powder soup and water’ was said to be similar to ‘digesting food’ because:

“When somebody is going to eat it, they are going to digest it, probably”

or, was found similar to ‘a cold drink left out in the sun’ because:

“You can like eat that in the bowl and after you could start to drink.”

‘Opposites’: The two situations were linked because one was perceived as opposite to the other in some way: it could be the changes involved in the situations or the properties of the elements participating in them that were seen to be opposites. The explanation that was offered, for example, for why ‘ice forming on a pond’ was similar to ‘acid rain eroding a stone statue’ was:

“Because that’s eroding whatever that is - the statue - and that’s forming. Like one of them is opposite, because one of them is forming ice and the other is eroding.”

‘Similarities’: The pupils attempted a kind of comparison between the two changes, either of their elements, or of the processes they saw as being involved in them, before identifying them as similar. So, both the following two quotations, which were meant to explain respectively why ‘making soup out of powder soup and water’ is similar to ‘digesting food’ and why ‘ice forming on a pond’ is similar to ‘acid rain eroding a stone statue’, were characterised as ‘similarities’.

“Maybe like, you know, when food is digesting and maybe, it could be like soup, it’s like powder and then they turn into a different form after that.”

“Both activities involve water.”

‘No reason’/‘unclear’: This refers to groupings which were not followed up by any explanation, or for which the explanation was unclear.

I then counted and compared the relative frequency of each of these categories in the first (A) and last (D) sets of transcripts.

‘Similarities’ and ‘opposites’

I also wanted to know about the kinds of similarities (or differences) the pupils identified between the changes, as well as about the way the pupils perceived each change in order to draw these similarities (or differences). I therefore singled out the

units categorised as ‘similarities’ and ‘opposites’ and looked to see if the similarities (or differences) identified emerged out of the comparison between the elements/objects participating in the situations, and/or their properties, or referred to the changes involved in them. An example of the first sort of similarity is given above; ‘ice forming on a pond’ and ‘acid rain eroding a stone statue’ were both seen as involving water. In the following excerpt the changes ‘a car windscreen being shattered’ and ‘ice forming on a pond’ are found to be similar based on the assertion that the objects in them have the same property; they are breakable.

“I got it. A car windscreen being shattered goes to the ice because ice...., a car can break and ice can break..”

Having identified this category of similarities (which refer to the properties of the participants) I further decided that it was worth noting which of these properties were of interest from the project’s point of view, that is, if any referred to the temperature, concentration or physical state of the substances involved in the situations.

If, now, the similarities happened to refer to the changes involved in the situations, was it that the pupils recognised similar processes happening in both situations, or that they identified similar changes happening in the properties or nature of the participants? These kinds of similarities could be more or less desirable from the project’s point of view. The attribution of a similar physical or chemical change to a pair of situations explicitly or even the attempt to reason about a similarity in such terms would be considered as desirable. For example in the following excerpt there is an attempt to reason about what is similar between ‘acid rain eroding a stone statue’ and ‘wood burning’ in terms that imply that the pupils tried to take into consideration the fact that both situations involved a change in the nature/substance of the objects involved. It has to be noted here that the pupils in question had not been taught about chemical changes in their lessons, and thus lacked the concepts to describe them.

P: *“These two. Because when a statue erodes...”*

P: *“...it’s breaking up.”*

P: *“And the wood burns...”*

P: *“...It’s melting the wood.”*

P: *“...It breaks the wood up.”*

P: *“It is going to...”*

P: *“...turn into ashes.”*

Desirable would also be an identification of a change in the temperature or in the physical state of the elements involved. The following justification is an example of this kind of reasoning. ‘Ice forming on a pond’ was found similar to ‘hot lava from a volcano turns solid’

“‘Cause that once was a liquid, and once this was like a liquid. That’s become a solid and so has that.”

On the other hand, a similarity drawn by treating the changes as ‘events’ or by identifying changes in properties such as hardness or shape would be less desirable. In the following excerpt ‘growing’ was treated as an ‘event’; although food was seen as relevant to ‘growing’, there is no indication that the pupil took into consideration in his/her account of the two changes any of the physical or chemical processes involved. This was despite the fact that s/he had met ‘growing’ in the classroom described as a process where matter ‘bunches together’. Comparing ‘a plant growing’ to ‘your body making extra fat’, this pupil said:

“That one is getting food from the sun and the thing, soil, and it’s growing and the man there is getting food from whatever he is cooking and he is going to grow as well.”

Two changes could be also seen as similar because they both involved a human action, or an action on a human being, or because they served the same pragmatic use. For example, the situations ‘hot lava from a volcano turns solid’ and ‘wood burning’ were thought of as similar because

“They both could burn you.”

This sort of similarities could be rather superficial and would be undesirable from the project’s point of view; after all, the project’s approach demands that pupils think about processes as happening or not happening by themselves without the intervention of a human.

‘Actual’ or ‘potential’ similarities

I also looked at whether the pupils identified similarities based on the features of the *given* changes - ‘actual’ similarities -, rather than on features of *possible* changes thought of as happening to the same participants - ‘potential’ similarities. The idea here was to see whether the pupils were able to identify the essential features of the changes presented to them or not. It appeared that in some cases the pupils reasoned that two situations were similar because it was possible for the change in one of them to happen to the object of the other under some circumstances. So, for example ‘plant growing’ was seen as similar to ‘fruit drying’ because

“Fruit can dry up and so can a plant. If you don’t give the fruit enough water, the fruit will dry up and if you don’t give enough water to the plant, the plant will dry up.”

I counted and compared the relative frequencies of the above categories in the first (A) and last (D) sets of interviews.

5.7.4.3 Pupils' spontaneous accounts of changes

Having described the kinds of similarities the pupils identified, I felt it important to look in more depth at how pupils reasoned spontaneously about each of the changes when they compared them. Was there any shift in pupils' spontaneous accounts of the changes as a result of the new approach? More particularly, for each of these accounts the questions I posed are:

- Did the pupils consider what was happening in the change? Or did they simply focus on the participants and/or what these could do?
- What terms did the pupils use to describe the change? Did they merely reiterate the words suggested to them by the name of the situation, or did they elaborate on these? When they did come up with their own descriptions of the change, did they use any of the project's terms, and if so did they use them correctly and/or appropriately?

The relevant extracts of the first (A) and last (D) sets of interviews were then codified accordingly; the relative frequencies for each category were compared across the two sets.

5.7.4.4 How pupils talked about changes common to first and last interviews

A third way of looking into pupils' performance in the 'grouping' task across the two sets of interviews was to compare how the pupils talked about the five changes which were common to both sets. This comparison was seen as complementing the previous two, but also as bringing them together and putting them in context, since it both extends their findings and exemplifies them for specific situations.

For each of these changes the additional questions posed here are:

- To which other situations was the change in question linked?
- Were these appropriate matches?
- Were there any appropriate matches which were not made?

For this analysis, the data for each of the groups interviewed were considered separately. Moreover, the comparison in question was done only for the groups whose composition remained sufficiently similar between the first and last interview (i.e. at least three out of the four pupils in the group were the same in both interviews).

5.7.5 ‘Matching’ and ‘comparing’ tasks: Comparison across each group’s interviews

The ‘matching’ (second) task in the interviews was expected to provide information about 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. Moreover, the ‘comparing’ (third) task was expected to show how well they managed to use these terms and ideas in comparisons of changes. Both tasks were also expected to provide evidence about how pupils made sense of and used the project’s abstract pictures, both when they reasoned about individual changes and when they compared these changes.

It was decided that the data concerning these aspects would be analysed for each group of interviewed pupils separately. For this purpose, after an initial examination of the transcripts, I chose to analyse three out of the four groups from each year, who had completed a full set of interviews (i.e. four). The groups excluded from the analysis consisted of pupils who had real difficulties in expressing themselves and/or reading in English.

The performance of each group across the four interviews was then compared and analysed for progress. Various considerations went into the decision to analyse the pupils’ progress by group and not by reflecting on all their individual performances together. By design, the interviews, following the curriculum approach, promoted group work. Thus, whereas the decision for the matching of a situation to an abstract picture ultimately lay with a particular pupil, the justification for this matching often evolved from group discussion, and consequently it would not have been appropriate to attribute it strictly to an individual. Also, most groups had a similar enough composition across the four interviews for one to maintain that each group portrayed similar patterns of interaction throughout.

However, I also considered it important to trace individual performances within a group, particularly in the analysis of the ‘matching’ task of the interview. In this task the unit of analysis was defined to include all the arguments expressed in the context of the matching of a given situation; the pupils’ individual suggestions for the match together with the relevant justifications were the sub-units of the analysis. The questions I posed in examining each such individual performance were:

- Did the pupils have any problems matching the situation to the abstract pictures? Which abstract picture did the pupil originally match the situation to? Was this an appropriate match or not? Was the match finally retained, changed or rejected?
- Did the pupil have any problem interpreting the abstract pictures?

- Did matching the situation to the abstract pictures help the pupil pay attention to the processes involved in the situation, or did s/he treat the relevant change as an ‘event’?
- What terms did the pupil use to describe the change? Did s/he merely re-iterate the words suggested to him/her by the name of the situation, or did s/he elaborate on these?
- How did the pupil use the terms and ideas suggested by the project in his/her account of the situation?

For the ‘comparing’ (third) interview task, consistent with its design, the unit of analysis referred to the comparison of two situations; each similarity or difference identified for this pair, as well as each attempt to reason about the suitability of the suggested (by the design) phrases for the two situations was treated as a sub-unit. The particular issues addressed by the analysis in this case were:

- Did the abstract pictures help the pupils to see similarities between the situations by considering the features of the processes involved?
- Did the pupils made use of the project’s terms and ideas in their identification of similarities and differences between the two situations? How did they use them in this case?

The analyses of the sub-units for each group of pupils were then assembled under headings, which reflect the important ideas introduced by the project for each Year, and therefore also the prompts (phrases and pictures) used in the corresponding interviews. Each group’s progress apropos these ideas was subsequently assessed. One can see two examples of the outputs of this analysis for Year 7 and Year 8 in sections 7.3 and 9.3 respectively.

5.7.6 Situations common to more than one interview: Comparison of explanations for each group

One other way of looking for pupils’ progress in the ideas introduced by the intervention was to compare their application of these ideas to various changes across the interviews. Subsection 5.7.4.4 explained why I looked at and compared the accounts the pupils gave *spontaneously* for the situations which appeared both in the first and last interviews. In this analysis I aimed to do the same, only this time for the accounts the pupils gave *aided* by the use of abstract pictures and phrases (i.e. as part of the interview tasks ‘matching’ and ‘comparing’).

The first step of the analysis consisted of identifying these common situations as well as the common prompts (abstract pictures or phrases) which were used for their

discussion in the interviews. How did the pupils apply the ideas represented by these prompts to the given situation in the respective interviews? As before, the comparison was done for each group of pupils separately and in total for three groups in each Year. A summary of this analysis for Year 7 can be found in section 7.4 and its equivalent for Year 8 in section 9.4.

5.7.7 ‘Grouping’ task: Comparison of all Year 7 last (D) and Year 8 first (A) interviews

Although the thesis is concerned with investigating the accessibility and usefulness of the ‘Energy and Change’ teaching approach on its own merit and not in comparison with existing teaching approaches - one reason being that both the approach in question and its objectives are novel (see also discussion in section 1.1) - it was thought that it was also important to see whether the pupils who had been exposed to this approach were able to reason about change at least no worse than the ones who had not. Evidence about this was obtained by comparing the performance of the Year 7 pupils in the last interview with that of the Year 8 pupils in the first interview, before teaching.

More specifically, what was compared was the Year 7 and Year 8 pupils’ performance in the ‘grouping’ (first) task of the last (D) and first (A) interviews respectively. This task’s main characteristic, as said before, is that it gives pupils the opportunity to discuss and compare a variety of changes spontaneously without the presence of visual or verbal prompts. This means that it was equally suited to pupils who had been exposed to the project’s approach, and to pupils who had not. It is true that the pupils of each class were not matched in terms of achievement, and that the Year 7 pupils were at the time of comparison on average six months younger than the Year 8 ones. However, there is no reason to think that on average the pupils of one class were of a lesser ability than those of the other, nor that this age difference of six months affected the performance of the Year 8 pupils significantly, bearing in mind the characteristics of the task and the lines on which its analysis was conducted (see subsection 5.7.4).

This comparison naturally followed the lines of the equivalent analyses for Year 7 and Year 8 (see subsection 5.7.4), which attempt to characterise the justifications pupils gave for grouping two situations, as well as to identify the features of the changes they paid attention to when they reasoned about particular changes. Those analyses were interested in seeing whether there was any change in the pupils’ performance over a period of time that could be attributed to their exposure to the teaching intervention. This comparison offers another way of investigating the same

thing; and more specifically the effects of the teaching approach on the Year 7 pupils' ability to abstract similarities between different changes, by comparing it with that of pupils of approximately the same age but who had not been taught using the project's materials. Since the former kind of comparison of pupils' performance in the first (A) and last (D) 'grouping' tasks was expected to yield only subtle trends (for reasons discussed in subsection 5.7.4.1) it was important to see whether these would also be detected in this new analysis. But, more significantly perhaps, this new comparison would look at whether the suggested teaching approach is a valid alternative which at minimum has the same effects as any other conventional teaching approach on how children reason about change.

For this comparison (reported in section 7.5) all transcripts from the Year 7 last interviews and the Year 8 first interviews were used. The first thing was to compare the relative frequency of the matches the pupils had attempted, characterised as 'similarities' or 'opposites'. I then compared the kinds of similarities and differences the pupils identified between two situations. Finally, as in the other two similar analyses, I looked at how the pupils talked about the changes that were common to the two sets of interviews and for which there was the expectation that a shift might have occurred.

5.7.8 Teachers' reactions

In section 5.7.2 I explained how I compiled the profiles of the two teachers whose classes I observed. There my main interest was to account for the experiences the pupils - the subjects of my research - had had in the classroom, so I gave a lot of weight to how the teachers actually dealt with the ideas of the project in the classroom, as well as what they thought it tried to achieve. In the current analysis, I looked at teachers from a slightly different point of view: I treated them as first users of the materials and I sought their reactions; I listened to them talking about how they would use the materials and observed them trying out the activities themselves.

The data used for this purpose came from the one-hour interviews I had carried out with each of the five science teachers of the school in which the research was based; and the questionnaires collected from the 42 teachers who had attended one-day in-service-training sessions about the project.

I first grouped the fifteen statements (comments about the approach), that appeared in the questionnaires and were also used as prompts in the interviews, under five thematic headings. The first contained statements that refer to the approach in general and the ideas behind it; I called this 'The approach: the science behind it'. The responses of the teachers to these statements were expected to reflect their

overall perception of the approach and its objectives. The second heading I called 'Children interacting with the materials', and contained the statements that refer to the accessibility of the materials to the pupils. The answers to these statements would tell me how well the teachers think that the project managed to transform its objectives into meaningful and manageable activities for the pupils. Under the third heading 'Relating to practical experiences' the teachers met statements that refer to the relationship between the activities suggested by the approach and practical work. Teachers were asked to say whether they think that this is a fruitful relationship or whether they think that practical work would be better. Under the fourth heading 'Teachers interacting with the materials' the statements referred to the possible gains teachers may have using the materials. Finally, heading five 'Incorporating the materials into the curriculum' held statements about how flexibly the materials can be used alongside existing schemes of work. These headings were by no means unique nor was the grouping of statements under them exclusive; they mainly served to organise the data for discussion.

I looked at the percentage of teachers agreeing and disagreeing with each statement, in order to get an idea of the general trends of their responses. These results were then discussed and contrasted with the corresponding findings from the analysis of the interviews with the science teachers of the school (see chapter 10).

CHAPTER 6

Year 7 Classroom Work

6.1 Introduction

This chapter and the following one (chapter 7) discuss the analyses of the data collected for the Year 7 class. In particular, this chapter is concerned with the pupils 'in the classroom' and contains details of the pupils' experiences in the intervention lessons together with case studies of selected pupils and their teachers.

In more detail, the rest of the chapter is organised as follows:

- Section 6.2 provides an account of the use of the project's activities in Year 7, based on the observation records taken during their use, the teaching notes that accompany them, and the interview I had with their designer (see also section 5.7.1). Its aim is to provide the reader with necessary background information concerning the pupils' experiences in the intervention lessons.
- Section 6.3 discusses the case study of the teacher of the class, based on classroom observation notes, the teacher's written evaluations of the project's activities, and the interview I had with her. This analysis serves two purposes (see process of analysis in section 5.7.2). It provides some further insight into the use of the project's materials in the classroom. Moreover, it is used, together with the case study of the Year 8 teacher (section 8.3) and the findings discussed in chapter 10, to address the research questions concerning teachers, in chapter 11.
- Finally, section 6.4 contains the case studies of six pupils. These trace the pupils' progress across the intervention, based on classroom observations and records of their written work (see process of analysis in section 5.7.3). As such they are used in the discussion of the conclusions for Year 7 (section 7.6), as well as in the discussion of the overall conclusions of the study in chapter 11.

6.2 Project's activities used in the Year 7 classroom

In this section I will attempt to give a detailed account of the experiences the pupils had in the Year 7 classroom using the project's activities. It is in relation to these experiences that pupils had that I will both seek to define what the desirable changes in pupils' ideas might be, and seek to justify any such changes should they come out of the analysis of pupils' interviews.

Table 6.1 shows the project's activities used in the Year 7 classroom and their places in the teaching of the topics 'Water', 'Air', 'Materials' and 'Life'.

Topic	Lesson	Activity
Water	5	A1 Backwards and forwards in the kitchen
	7	A2 Pictures of mixing
	10	A3 Dissolving - speeding it up
	11	A4 Mixing and 'unmixing'
	15	A6 Pictures of separating
	16	A5 Mixing and 'unmixing' - 'downhill' and 'uphill'
	18	A7 'Spreading out' and 'bunching together'
Air	2	C1 Air - squeezing, stretching, pushing and pulling
	4	C2 Moving gases around
	5	C3 Gases: spreading out and mixing (renamed: Smells and pollution)
	12	C7 Evaporating (renamed: Evaporation and condensation)
	14	C8 Evaporation - speeding it up and slowing it down
Materials	1	C4 Objects and substances
	3	F2 Wearing out
	6	E4 Getting hotter and colder
	7	B2 Measuring temperature
	9	B3 What happens next?
	11	C5 Putting changes into groups
	12	C6 Melting, freezing, evaporation, condensation
Life	4	D1 Water and life D2 Keeping a balance
	5	D3 Getting out of balance
	8	D4 Spreading and bunching in living things

Table 6.1 Project's activities used in Year 7 and their places in the topics

The above activities for Year 7 invite pupils to pay attention to differences in concentration and to identify matter 'spreading out' and 'bunching together', 'mixing' and 'unmixing'; to pay attention to differences in temperature and to

identify differences disappearing or appearing; and finally to pay attention to changes of state and to identify the changes in the nature and concentration of the substance(s) and the changes in the accompanying temperature differences. Furthermore, they ask pupils to draw on their experience and consider at an elementary level the direction of changes, that is, the fact that some processes may happen easily but are more difficult to reverse.

According to the project co-director Richard Boohan* who designed the pupils' materials for the project, the ideal progression of these ideas would be something along the lines of looking at 'mixing' and 'unmixing', 'spreading out' and 'bunching together' of matter at first, then going on to look at temperature differences and their uses, and then to bring the two together and think about changes of state.

The topic 'Water', which is taught in Year 7 in the school in question, lent itself to the introduction of concentration differences. However, the school's plan for this topic included the introduction of temperature changes and changes of state in relation to water, which would more comfortably - from the project's point of view - have gone after pupils had looked at work on temperature differences and insulation, which were met in the topic 'Materials'. Furthermore, the pupils' activities used in the topic 'Life' would have gone better conceptually with the activities about 'spreading out' and 'bunching together' as they were also concerned with concentration differences, only this time in living systems.

6.2.1 Topic: 'Water'

6.2.1.1 'Backwards and forwards in the kitchen' (Activity A1)

This was the first activity from the project that the pupils met in this topic. The activity is about dissolving, and the idea behind it is that "*changes in which things are mixed happen more easily than changes in which they are 'unmixed'*" (Boohan, 1996a - Theme A, p2)**. It was used in the fifth lesson on 'Water'; in the previous four the pupils had met issues concerning the importance and use of water, but had also talked about water in the solid, liquid and gas state and had done an experiment heating up ice and measuring temperature changes.

* interviewed about the 'Energy and Change' project in November 1995

** In the interest of brevity, hereafter every quotation from the project's teaching notes will be referred to as (Theme X, pY), that is using the letter of the corresponding theme in the publication (Boohan, 1996a) and the number of the page (of this theme) in which the quotation appears.

Anna, the teacher of the class, had already introduced the terms ‘dissolving’ and ‘solution’ and had already asked the pupils to consider whether it was easier to dissolve a sugar cube and get sugar water, or get a sugar cube out of sugar water, when she showed them the transparency that accompanies the activity. The transparency introduces the idea of changes which happen more easily in one direction, by giving two examples of such changes; a mug breaking is said and shown in a picture to happen more easily forwards than backwards, while an onion being made from a chopped onion is said and shown to happen more easily backwards than forwards. Anna discussed the examples with the pupils and further asked them if they thought it is easier to boil an egg or to ‘unboil’ it. The point she aimed at making was that one could not get the egg back once boiled, as it is a chemical reaction. In the discussion of the above examples the question of whether a change was easier forwards or backwards turned out most times to be a question of whether the reverse change was feasible e.g., whether one could get a mug out of a broken mug.

It was an individual activity which entailed cutting out twelve pictures depicting six changes - once forwards and once backwards - and sorting them out in two groups, an ‘Easier forwards’ group and an ‘Easier backwards’ group. The pupils then had to stick the pictures of the ‘Easier forwards’ group in their books and write why they thought those changes go forwards more easily than backwards.

6.2.1.2 ‘Pictures of mixing’ (Activity A2)

The second project activity was used in the seventh lesson. It followed a lesson on ‘dissolving’ where children had been introduced to the process and to its relevant terminology and had gained experience in dissolving different substances in water. Anna had given an account of the dissolving process in terms of particles using as an example the dissolving of a sugar cube in water.

The activity ‘Pictures of mixing’ is *“about matching changes to abstract pictures involving mixing. It also encourages pupils to think about mixing as a process in which substances ‘spread out’”* (Theme A, p2).

The transparency that accompanies the activity introduces the conventions of the abstract pictures with matched examples. Anna explained the conventions and talked about the changes on the transparency.

The activity was done by the pupils individually. They needed to match eight changes to nine pictures of mixing and write about each change. Anna did the first match with the whole class, and drew the pupils’ attention to the fact that when

things dissolve they do not disappear, but rather spread out. She also encouraged them to write about the changes using the words suggested on the sheet, namely ‘mixing’, ‘spreading out’, ‘solid’, ‘liquid’, ‘dissolving’, ‘solvent’, ‘solute’, ‘solution’, ‘soluble’ and ‘insoluble’. Three of the abstract pictures in the activity show impossible changes in which something ‘disappears’ with the solvent remaining unchanged. Anna at some point indicated them to the children, thus making the activity less demanding.

6.2.1.3 ‘Dissolving - speeding it up’ (Activity A3)

“The activity is about the factors which affect the rate of dissolving. Again, it emphasises dissolving as a process of ‘spreading out’” (Theme A, p3).

The activity was used for individual work in the tenth lesson on ‘Water’, following two lessons on fair tests. In these the class had talked about what fair tests are and had conducted experiments where they had tested how different factors affect the rate of dissolving. Dissolving had been again accounted for in particle terms, but there had been no emphasis on the ‘spreading out’ of the particles.

The worksheet containing the activity was used also as a transparency by Anna. She presented the four ways depicted in it for making things dissolve faster - exemplified for the dissolving of sugar in water - and introduced the corresponding pictures. The children had to cut out and match six changes to the suggested ways of speeding up dissolving and then to write about how each one happens. Anna encouraged them to use the term ‘spreading out’ in writing about the changes.

6.2.1.4 ‘Mixing and ‘un-mixing’ (Activity A4)

In the next lesson the students met the ideas of mixing and ‘un-mixing’ and, with the aid of an activity that they did as a whole class, they were shown that it is easier to mix things/substances than to ‘un-mix’ them. The transparency ‘Mixing and ‘un-mixing’ (Activity A4) prepared by the project to accompany this lesson was not used. This transparency introduces the ideas that mixing is a ‘downhill’ change and ‘un-mixing’ is an ‘uphill’ change and reinforces the use of the terms ‘spreading out’ and ‘bunching together’ in connection with the processes of mixing and ‘un-mixing’. The above ideas were not introduced in the classroom, and the terms ‘spreading out’ and ‘bunching together’ were scarcely used.

6.2.1.5 'Pictures of separating' (Activity A6)

This activity was used in the fifteenth lesson on 'Water'. *"The activity is about matching changes to abstract pictures involving separating. It also encourages pupils to think about what similar processes have in common"* (Theme A, p5).

The pupils had spent the previous three lessons doing practical work on separation using different techniques. When writing about the purification of rock salt, Anna had insisted that they mentioned whether it is easier to mix or 'unmix', reinforcing in this way the idea that it is easier to mix things than to 'unmix' them.

The worksheet containing the activity 'Pictures of separating' was first used as a transparency. Anna checked that the pupils could understand what the pictures showed; the conventions used are basically the same as those used in the activity 'Pictures of mixing', with one addition. She encouraged them to describe the pictures using the terms 'solid', 'liquid', 'solution', 'mixing' and 'separating', and for most of the pictures she asked the pupils to suggest examples that could correspond to the changes shown in them.

For the activity the pupils had to cut out and match twelve changes to six pictures of separating; two changes corresponded to each picture. After identifying the matches, they had to write what each pair of changes had in common. Anna helped them by suggesting for one such pair what they could write, putting emphasis on the use of the appropriate terms.

6.2.1.6 'Mixing and 'un-mixing' - 'downhill' and 'uphill' (Activity A5)

"This is a brief activity intended to make the point that mixing 'just happens' but 'unmixing' does not 'just happen'" (Theme A, p4). It was used in the sixteenth lesson and was followed by an investigation on cooling hot copper sulphate to form crystals.

6.2.1.7 'Spreading out and bunching together' (Activity A7)

This was the last activity from the project's materials used in this topic. *"The aim of this activity is to encourage pupils to use appropriate language for describing processes of mixing and separating"* (Theme A, p5).

Anna first checked that the pupils understood what the processes of 'spreading out' and 'bunching together' were and invited them to suggest alternative words to describe them. She found it difficult to relate these words to 'mix' and 'unmix', and this resulted in confusing statements which made little sense, e.g. *"'bunching together' is not dissolving and is not mixing up"*.

The transparency that accompanies the activity illustrates what pupils should do on the worksheets, which is to choose the correct words from a set of alternatives, so that the sentences formed are correct for the given change. Having done this they are then given four changes which they are asked to describe in their own words. For this second part, Anna instructed pupils to try to use the words suggested in the first part, and as a result most pupils ended up writing sentences identical to the ones in it. The answers given in the first activity had been corrected by Anna and myself prior to this.

Other lessons:

In the last lesson of the topic there was a discussion about acid rain. Anna managed to extract from the pupils the idea that gases dissolve in water, and in the context of the investigation pupils did to find out what happens when acid falls on marble, she tried to apply knowledge visited in previous lessons about the factors that affect the rate of dissolving. She also tried to reinforce the use of the term ‘spreading out’, but unfortunately did that unsuccessfully by relating it to the chemical reaction of sulphur dioxide with water to give sulphuric acid.

The end-of-topic test was prepared by Anna and included a few of the project’s ideas. Two of the abstract pictures were used to represent mixing and dissolving; the names of the processes were asked for as well as an example of one of them. Moreover, pupils had to identify in what four ways one could make things dissolve faster, and for soapy water becoming washing-up liquid and water they had to say in which direction the change happens more easily and explain why they thought that is.

6.2.2 Topic: ‘Air’

The first lesson on this topic was dedicated to the idea that air is real, and while one cannot see it, one can see what it can do. Anna ran four demonstrations which were meant to prove that air existed. For all four of them she gave accounts of what happened to the air particles, trying to use whenever she thought appropriate the terms ‘spreading out’ and ‘bunching together’. The pupils had then to write about the demonstrations, explaining what happened to air in each.

6.2.2.1 ‘Air - squeezing, stretching, pushing and pulling’ (Activity C1)

This activity was used in the second lesson. *“The activity is about the way in which air is distributed in containers. It is concerned with thinking about amounts, volumes and pressure of air in different situations”* (Theme C, p2).

In the activity the pupils were shown four situations and were asked to choose the pictures they thought best showed the ‘Before’ and ‘After’ instances of these changes and to explain their choices. Before they started on the activity, Anna with the aid of a syringe showed them that air can be squeezed and made to ‘bunch together’, or be stretched and made to ‘spread out’.

In trying to do the first two situations with the whole class, Anna found herself confused about what the pictures were meant to show. However, even after I had explained them to her and pointed out that some pictures showed something impossible, e.g. a void container, or a container with irregularly concentrated air in it, she failed to draw pupils’ attention to the changing features of the pictures which are the amount, the volume and the pressure of the air. She pointed out to the children the ‘impossible’ pictures, but did not tackle in depth the issue of how air is distributed in containers.

At the end of the worksheet there is some extension work, in which pupils are asked to draw their own pictures. Only a few pupils did it.

6.2.2.2 ‘Moving gases around’ (Activity C2)

The second activity from the project’s materials was used in the fourth lesson on ‘Air’. The one before that aimed at establishing the facts that air is a mixture of various gases at different concentrations. In the same lesson Anna had also shown the pupils that not all gases are invisible by making nitrogen dioxide from copper and nitric acid.

“The aim of this activity is to give pupils experience of handling a gas and appreciating that although it is invisible, it can be manipulated in a similar way to a liquid” (Theme C, p2).

The worksheets suggested six different activities that the pupils could do in groups and which involved manipulating carbon dioxide gas. All pupils seemed to do the first three, while no one seemed to arrive at doing the last. According to Anna this happened because some of the activities proved fairly demanding for the pupils; some activities also did not work and the pupils lost their motivation.

6.2.2.3 ‘Gases: spreading out and mixing’ - later renamed ‘Smells and pollution’ (Activity C3)

This activity was used in the next (fifth) lesson. It *“is concerned with thinking about the idea that there are different gases, and that they can spread out into each other and mix together”* (Theme C, p3).

Anna started the lesson by drawing on pupils' knowledge about the processes of 'mixing' and 'spreading out' and on their experience in manipulating carbon dioxide, in order to introduce the idea that gases spread out and mix by themselves. She, however, once more seemed to confound the issues by suggesting that spreading out and mixing is the same thing. The activity was then introduced by two demonstrations which showed gases 'spreading out'. In the first one some garlic paste was introduced at one end of a long cardboard tube with holes along it at intervals for pupils to put their noses in. Pupils were told to move their noses away as soon as they smelled the garlic. The demonstration was followed by a discussion about what had happened and why not all the pupils who had put their noses in the holes had smelt the garlic at the same time. Anna encouraged them to use the ideas of mixing and 'spreading out' in their explanations. She then went over what is written on the worksheet, making sure the pupils could make sense of what the pictures show.

In the second demonstration Anna injected some carbon dioxide into the bottom part of a gas jar with a syringe, and then using the syringe removed samples from different parts of the gas jar - bottom, middle, top - and tested with limewater for the presence of carbon dioxide. All the tests were positive, and Anna made the point that carbon dioxide had mixed with the air and had spread out.

The worksheet contains three activities. In the first one pupils are asked to explain why in the 'garlic' demonstration one can eventually smell the garlic. Anna asked them to write about the demonstration, using the words 'spreading out' and mixing. In the second activity the pupils had to draw their own pictures to show what is happening in each of three changes, as well as explain it in writing. Both activities were done individually by the pupils. The third activity aims to encourage pupils to think back to earlier ideas about 'mixing and unmixing', 'spreading out and bunching together' and to relate these to gases. The idea that mixing happens more easily than 'unmixing' comes out once more reinforced. For three pairs of changes children are called to identify similarities and differences and to indicate the one that happens more easily. Anna's class had only time to look at the first of these pairs of changes and talk about it briefly in a whole class discussion.

Other lessons:

In the following six lessons (two weeks time) the teaching of science in that class was undertaken by a student teacher. It was agreed that no activities of the project would be used during this time. The issues covered by him concerned air pressure and its measurement, the use of air, and burning with oxygen. The account of 'air pressure' was given basically in a macroscopic way, with only pictorial references to

the air particles. In the lesson about burning with oxygen the pupils carried out a practical, burning several substances in air and in oxygen to see the difference.

6.2.2.4 ‘Evaporating’ - later renamed ‘Evaporation and condensation’ (Activity C7)

This was the fourth activity of the project used in the teaching of ‘Air’. *“In this activity, pupils explore in more detail the nature of evaporation and condensation”* (Theme C, p5).

Anna reminded the pupils of the processes of evaporation and condensation by bringing in examples of such changes met in everyday life, and accounted for them in particle terms using the words ‘spreading out’ and ‘bunching together’. For the change of liquid water into steam, for example, it was said that water particles spread out, while for the change of water gas into water liquid they bunch together. To demonstrate the latter process, Anna showed the pupils a glass which had water and ice cubes in it and asked them to look at the condensation on the outside of the glass; the water on the outside had come from the air and had bunched together on the glass.

The transparency that accompanies the activity is intended to encourage class discussion about the nature of evaporation and condensation (e.g. what is happening to the water, is it disappearing, is it spreading out, etc.). Anna went over these questions with the class and reminded them what the pictorial conventions for ‘liquid’ and ‘gas’ were.

In the activity pupils are given 12 changes and are asked to identify the changes which involve evaporation, and then to give reasons why they chose to include or exclude some of the examples. Anna encouraged them to write about these changes using the ideas from the transparency.

6.2.2.5 ‘Evaporation - speeding it up and slowing it down’ (Activity C8)

In the fourteenth lesson pupils met the last of the project’s activities for this topic. *“The activity is about the factors which affect the rate of evaporation and emphasises evaporation as a process of ‘spreading out’”* (Theme C, p6).

In the previous lesson, the class had done some related experimental work; they had talked about what one could do to make something dry faster, and then applied and tested these ideas for a wet paper towel. Anna had insisted on the use of the term ‘spread out’ and ‘mix’ for describing what happens to water particles when a paper

towel dries out. She had also intended to explain how wind and heat speeds up this process.

The worksheet of the activity was also used as a transparency to introduce four factors which affect the rate of evaporation. Anna went over these factors with the class, checking that they could understand what the abstract pictures showed and reminding them what they had done in the related investigation. At the bottom of the worksheet there is a list showing some places one could leave washing to dry. For each place the pupils had to answer in their books whether they thought the water would evaporate quickly and why they thought that. Anna suggested that in order to answer the second question they would have to refer to the four ways of speeding up evaporation suggested on the worksheet, and tried one example with the whole class.

Other lessons:

The three following lessons were given by the student teacher and were about breathing and testing air on the move. A written test administered also by him dealt with the issues of air pressure, its measurement, and the process of breathing.

6.2.3 Topic: 'Materials'

6.2.3.1 'Objects and substances' (Activity C4)

This project's activity was used in the first lesson of the topic 'Materials'. *"This activity provides a starting point for a discussion of the idea of 'substance' and distinguishes this from that of 'object'"* (Theme C, p4).

Anna, starting the lesson, defined the word 'materials' as 'the stuff things are made of' and prompted the children to give her examples of different materials. She then gave them the worksheet; they had to cut up a list of twenty things, sort them out into 'objects' and 'substances', and then match each object with the substance it is made from. Anna tried out one of the examples from the worksheet with them in order to show them what they had to do. I noticed that she did not explain the word 'substance'; she rather used it as a synonym of 'material'.

The pupils worked individually on the activity and all their answers were checked. They finished it so quickly that Anna had to give them a further list of objects and substances to sort out. Following my suggestion she included in it the words 'ice cube', 'steam' and 'water'.

6.2.3.2 'Wearing out' (Activity F2)

The second of the project's activities was used in the third lesson on 'Materials'. *"The activity makes the distinction between changes to objects and changes to substances, as a way of introducing the essential nature of a chemical reaction"* (Theme F, p3).

Anna explained the conventions used in the pictures in the worksheet and talked about the examples given in it. She further asked the pupils to suggest more examples where the object changes but the substance stays the same or where the substance changes to a different substance. For the activity the pupils had to group ten changes in two groups according to whether they are mechanical or chemical changes, that is whether the object changes or the substance. Anna took some time to explain some of the words that appeared in the descriptions of the changes on the worksheet. The worksheet also asks the pupils to look at the changes in each of the groups and think about whether it is possible to get the object or substance back to the way it was at the start, how this could be done and if it would be easy or difficult. Anna did not give any guidance to the class about how to deal with these questions, nor did she follow them up with discussion.

Other lessons:

In the following two lessons the class talked about the properties of different materials and did a practical where they made concrete.

6.2.3.3 'Getting hotter and colder' (Activity E4)

"This activity is intended as a stimulus to discussion about what happens in various situations in which there are temperature differences" (Theme E, p4).

This activity was used in the absence of Anna, with the aid of a supply teacher. On the worksheet there are six changes. Each change is depicted by two pictures, one showing its 'before' and one its 'after' instance. For some of the changes these pictures are in the wrong order. The pupils are asked to specify for each of the changes which picture comes first and write down the reasons for their choices. In all changes, temperatures become equal in the end, though this proved not to be easy for most pupils to appreciate. Most pupils worked individually on the activity, while some discussed their choices in small groups. Pupils' answers were checked but no class discussion followed up the activity.

6.2.3.4 ‘Measuring temperature’ (Activity B2)

“This is a practical activity in which pupils gain experiences in looking at situations in which temperatures are becoming equal” (Theme B, p3).

Anna presented the activity saying that it was about looking at measuring temperature and at how temperatures change. The activity consists of six tasks. These tasks were set up as a circus round the classroom; the children had first to read about each task, predict what would happen, write it down giving the appropriate explanation, then do the experiment to check and if they were wrong, explain why. Anna strongly insisted that they explained first their predictions and then if they were wrong, why they were mistaken. She also asked them to draw a diagram to show each of the tasks.

One of the tasks asked pupils to think whether blocks of wood and metal left in a room have the same temperature. The pupils were surprised to find out that although the metal block felt colder, it was at the same temperature as the block of wood. Anna explained this observation by saying that how the block felt depended on the material it was made of, and that metal feels colder because it conducts heat. She also later explained that a thermos flask is especially designed to prevent things put in it from changing temperature.

Other lessons:

In the lesson that followed the class did an ‘insulation’ practical where they drew cooling curves for hot water with and without insulation.

6.2.3.5 ‘What happens next?’ (Activity B3)

This was the fifth of the project’s activities used, in the ninth lesson on ‘Materials’.

“The aim of this activity is to encourage pupils to pay attention to differences in temperatures, and to make the point that eventually these temperatures will become equal” (Theme B, p3).

The pupils did the activity in the absence of Anna who had to leave the classroom after she presented the activity to the pupils. On the worksheet pupils are given six changes which are about things at different temperatures; these two temperatures for each change are shown semi-quantitatively with the aid of a picture of two thermometers. Children have to think what eventually happens to the temperatures in the changes and choose the picture (one out of eight suggested) they think shows this best. They are also asked to consider the possibility that some of the pictures may show something which could never happen, and to try to identify them.

In introducing the activity Anna drew pupils' attention to the fact that for each change the pupils had to decide first what the two thermometers in the first picture represented and then to think about what would happen to them. The activity was done by pupils individually; no class discussion followed it up. It was followed by an activity from the 'Active Science 1' textbook (Coles, Gott and Thornley, 1988), for which the pupils had to read a text on 'Keeping warm' and answer some questions based on it.

6.2.3.6 'Putting changes into groups' (Activity C5)

In the eleventh lesson on 'Materials' the class used the above activity. *"This activity is intended as a starting point to stimulate class discussion about the nature of changes of state - melting, freezing, evaporation, condensation"* (Theme C, p4).

On the worksheet there are twelve changes which illustrate some examples of melting, freezing, evaporation and condensation. Pupils have to cut them out and sort them into groups showing similar changes. For each group, they then have to write a sentence explaining why the changes in a given group are similar.

Before starting the activity Anna asked the pupils to remember the names of the four changes of state. She gave concrete examples for most of them, e.g. water turning into ice, but also described them in terms of the nature of the change to the substance involved, e.g. liquid turning into solid.

The activity was done by the pupils individually, their groupings were checked and pupils were directed towards a 'correct' grouping. The pupils who finished early were given the activity 'Melting, freezing, evaporation, condensation' (Activity C6) also from the project's materials.

6.2.3.7 'Melting, freezing, evaporation, condensation' (Activity C6)

"This activity is intended to make explicit to pupils the nature of changes of state, and the temperature differences which make them happen" (Theme C, p5).

Just as in the activity 'Spreading out and bunching together', pupils circle words on the sheets so that the sentences make sense. The first two sentences for each change are about the nature of the change to the substances involved and the name of the change, while the third sentence is about the temperature difference which makes the change happen. At the end of the worksheet, there are six changes which pupils are asked to describe in their own words.

Only the more able students found time to start this activity in that lesson. The rest did it in the lesson that followed, while Anna was absent.

Other lessons:

In the last two lessons of the topic the class watched the video ‘River of Rock’ which dealt with changes of state, and discussed the considerations that go into choosing the right material(s) to make different objects.

The test paper given to the pupils at the end of the topic ‘Materials’ was developed by the project and referred to both the ‘Air’ and the ‘Materials’ topics (as these were agreed to be considered as one unit).

6.2.4 Topic: ‘Life’**6.2.4.1 ‘Water and life’ (Activity D1) and ‘Keeping a balance’ (Activity D2)**

The first use of project’s activities took place in the fourth lesson of this topic. The first one *“introduces the idea of a ‘steady state’, and that living things ‘keep a balance’ by a flow of water through them”* (Theme D, p2), and the second one *“relates the flow of water into and out of a living thing to ideas of ‘bunching together’ and ‘spreading out’”* (Theme D, p3).

In the previous lessons the class had looked at what is needed for growth and what the right conditions for germination are. They had also discussed what happens to water in plants and animals. Anna had insisted on the pupils using the notions of ‘spreading out’ and ‘bunching together’ when they reasoned about it, and thus had established that all living organisms ‘bunch together’ water molecules when they take in water but also ‘spread them out’ in various biological processes, some of which involve evaporation. She had also introduced the idea that humans need to balance the amount of water in them, and had illustrated this by a plastic drinks bottle with a tube connected to a tap going in at the top and a tube leading from the bottom going into the sink; when the tap is regulated, the water going in equals the water coming out, with the water in the bottle staying at the same level. This idea was suggested in the teaching notes of the project. Anna had helped the pupils see the bottle as a model of a human being or of a plant, and had explained what the incoming and outgoing water would be in each case. The pupils had had to write about the demonstration using the words ‘spreading out’ and ‘bunching together’.

In the activity ‘Water and life’ pupils are introduced to four situations involving containers of water and are asked to match ‘a lake’, ‘a plant’ and ‘a human’ to these situations. Anna spent some time talking with the children about these situations and their corresponding pictures on the worksheet. She pointed out to them the one that corresponded to the demonstration of the previous lesson and provoked a discussion

about whether water disappears when evaporated. Although this was not explicitly requested in the worksheet, Anna asked the pupils to justify their matches in writing. Their choices were discussed and emphasis was put on identifying the best match, if more than one were possible.

To demonstrate evaporation from plants and humans Anna made use of a selection of practical tasks suggested by the project in the teaching notes that accompany the activity. One, for example, involved tying a plastic bag around a hand and observing what happens, another using a potometer to show water movement through a plant when it is dried with the aid of a hair dryer.

In the activity ‘Keeping a balance’ pupils are presented with six changes and are asked to think whether water is ‘spreading out’ or ‘bunching together’ in each of these and to tick the appropriate box. This task is followed by one where they have to circle the correct words in a short text which talks about what happens to water in a lake. Finally they are asked to write in their own words what is happening to water in a plant and the human body.

The class was given this activity to work individually. The pupils’ answers for the first two tasks were discussed. In writing their own explanations Anna suggested that the pupils used the sentences that appeared in the short text of the ‘circling’ task after they adapted them for the new situations.

6.2.4.2 ‘Getting out of balance’ (Activity D3)

“The activity looks at some of the factors which affect the rate of evaporation from a plant and from a human” (Theme D, p3).

This activity was used in the fifth lesson on ‘Life’. The class had first a short discussion about the meaning of the word ‘balance’ and then Anna introduced the activity. She explained what the pictures on the worksheet show and tried the first question with the whole class. The children had to decide in which weather conditions a plant which does not get enough water will wilt faster, and in which situations a human who does not have enough to drink, will feel thirsty faster. They also had to explain in writing their answers to these questions, and Anna hinted that in doing this they should think about the factors that affect the rate of evaporation.

The pupils worked on the activity individually. One of the questions seemed to present difficulties for most of them. The question was about whether we feel thirsty faster travelling in a car with the windows closed or with the windows open. Most pupils seemed to think that one would feel thirsty faster if the windows of the car

were closed. Anna corrected them; in her explanation she reminded them that particles spread out faster in open containers.

Other lessons:

In the following two lessons the class discussed pregnancy and classification trees.

6.2.4.3 ‘Spreading and bunching in living things’ (Activity D4)

“This activity extends the earlier ideas of the ‘spreading out’ and ‘bunching together’ of water to include a wider range of substances and processes” (Theme D, p4).

This was the last of the activities of the project that was used in this topic. Anna introduced the ideas behind this activity with the aid of the transparency that accompanies it. She explicitly made the point that while it seems natural to think of growing up as a ‘spreading out’ change, it is actually a ‘bunching together’ change, since one needs to bring together substances from food for growth.

In the worksheet pupils are asked to categorise nine changes in living things as examples of ‘spreading out’ or ‘bunching together’ and to explain why they made these choices. Anna introduced the abstract pictures of ‘spreading out’ and ‘bunching together’ at the top of the worksheet and stressed that in justifying their choices the pupils should focus on what is happening inside humans or plants.

The activity was worked individually and the pupils who finished early were asked to write two examples of their own. At the end of the lesson, Anna went over the correct answers and their justifications; in doing so she repeatedly referred to ‘substances ‘bunching together’ or ‘spreading out’.

Other lessons:

The ideas discussed in the topic ‘Life’ were examined in an end-of-topic test prepared by the project.

6.3 Case study of Year 7 teacher: Anna

Anna, the Year 7 class teacher, is a dynamic and competent teacher. She is very good at managing her class; she knows how to let pupils take initiatives while she keeps tight control of the class.

Did Anna grasp the general long-term aim of the project, what the project tried to achieve as a whole? The evidence is not very conclusive. She certainly saw the project as a different approach to teaching certain things, but not as introducing ideas

that have not been taught before in the lower secondary school. Commenting on the Year 7 work she said:

“It’s not really meant to introduce a new idea, is it? It’s just meant to be a different approach to teaching something that’s not being taught very well at the moment.”

She saw the approach as trying to get the children to think about the causes of changes, as trying to provide better explanations of why things happen, but it seemed that she did not see these explanations in their unity deriving from the Second Law of Thermodynamics. The materials provided her with a set of a few powerful ideas expressed in simple words she could carry from one lesson to another and use them to explain a variety of changes. She saw these ideas as bringing coherence to her teaching

“...you tend to do lots of isolation sort of bits and pieces especially in, for example, the energy topic, and you don’t really see a progression or a theme, and you definitely do when you’re using those materials.”

and as facilitating children in their transition to GCSE science and that’s why she was enthusiastic about the materials. Her agenda seemed to be very pragmatic; her two concerns were to enrich her teaching, go beyond the description of what happens and talk about what causes things to happen in a language that would be easy for pupils to understand and use and which would be scientifically correct; and to prepare the pupils as well as possible for when they would get to their GCSEs.

Anna really welcomed the use of the project’s materials in her lessons and accepted easily the suggestions Richard Boohan (co-director of the project) made about how these could fit in the existing schemes of work for the three topics chosen. As to the researcher’s (i.e. my) presence in the classroom, she did not appear particularly happy about it at the beginning. She soon however got used to it and seeing me work mainly with the pupils she felt less threatened. She ended up asking for my help and/or my opinion concerning the use of the materials and children’s reactions to them several times during the intervention.

It is true that Anna did not have the overview of what objectives were sought for the Year 7 pupils from the project’s point of view, nor did she have the materials to be used a long time in advance to study and reflect on them. Due to the nature of the development of the materials, where new materials were developed only after the project had received some feedback concerning the use of the previous ones, some of the materials were only made available to her a week before the lesson. It is therefore unfair to ask whether while she used them she could see the ideas involved achieving something in the long term. And when she did, mainly after having used them, this

was I think in terms of better achievement of pupils in traditionally difficult parts of science at higher level.

Having observed Anna teach the project's materials for a period of approximately eight months I have formed some impressions about how she coped in the classroom with some of the characteristics inherent in the design of the materials. The terminology used in them is one for example. The terms 'spreading out' and 'bunching together' or 'easier forwards' and 'easier backwards' were terms heavily used in the Year 7 materials and reflected ideas very important for the project. Anna, certainly at the beginning, did not feel very comfortable using them. She complained that the project was imposing on children difficult words which moreover were not scientific. I think this comment demonstrated more her own feelings and confusion about the terms used. It is interesting that in the interview I had with her at the end of the year she said:

"No... no, I don't think you could class bunching and spreading as a special vocabulary, I don't think so. [...] using simple words like spreading out and bunching together has made the children understand it straight away and once they've got that understanding then you can use the proper words."

I think again that she saw these words mainly as simple words she could use to describe what is happening to the particles during a process of change without paying so much attention to the importance of these ideas for the project which was that one is happening spontaneously while the other is not. Anna kept bringing them up in her lessons, to the point where the pupils became accustomed to read her cues and answer in these terms even if it was not appropriate to do so. However, she did not give them any 'life'; she used them a bit dryly as if they were names of processes. She would often say for example 'mixing is spreading out' or ask the pupils if 'bunching together is dissolving' but would not often talk of 'something spreading out into something else' or draw pupils' attention to what was bunching together, if anything. I am afraid, in other words, that in trying to make the pupils use the suggested words she often encouraged a mechanistic use of them rather than a use that reflected a deeper understanding of the ideas involved. That is not to say that she used these ideas only in abstract contexts; on the contrary, she always tried to provide some concrete examples from children's everyday experiences to apply these ideas to. Moreover, to help pupils visualise the actions of 'spreading out' and 'bunching together' she asked them to role play them. It is also true that as she grew confident with the use of the new terms, she applied them more and more spontaneously and consistently. However, I also found that she did not fully explore the opportunities that were presented to her by the materials to make the point that

the ‘spreading out’ of matter is a downhill change while ‘bunching together’ is an uphill change.

Having commented on Anna’s use of the terminology introduced by the project, it is important to say that these were not the only words Anna tried to engrave on children’s minds. The teaching of important ‘scientific words’ was a very high priority for her. The spelling of words like ‘solid’, ‘liquid’, ‘solvent’, ‘solution’ etc., were tested regularly and their presence was requested in children’s explanations, both oral and written. I think that this policy of hers was dictated by the fact that more than half the class consisted of bilingual pupils of whom some had very poor knowledge of English.

Another idea which is very important to the project is that of temperature differences driving change. This comes up in the Year 7 work only in the teaching of the changes of state. Anna seemed not to pay any attention to this idea and taught them in the conventional way focusing thus only on the nature of the substances before and after the changes and not on the temperature differences which drive them. It is unclear to me if this says anything about her understanding of this idea. Interestingly, talking about this activity in the interview she said:

“The ‘Putting changes into groups’ is a good one because it shows the...it really gets them to think about what the particles are doing regardless of the temperature.”

Anna, indeed was very keen to talk about particles but most of the time attributed to them rather macroscopic properties. She certainly moved between the macro and micro realm a little carelessly. This was more obvious in the case of the use of ‘spreading out’. So, she would talk of the sugar particles spreading out in the water, but also of a jersey being spread out to dry faster. Thus the ‘Life’ materials in which the macro descriptions of changes contradict the micro ones, e.g. when a baby’s bones grow the particles bunch together and not spread out, were met with more scepticism and uncertainty by Anna.

“[...] it’s quite an abrupt sort of very different kind of idea.”

The use of abstract pictures is another characteristic of the materials. Anna did not seem to have any problems with the use of abstract pictures, although it is true that in the Year 7 materials they do not feature heavily. Only once, at the beginning she seemed to express the feeling that the children were daunted by them, but by the end she thought that once the children had had explained to them what the conventions meant they did not have any problems with the pictures.

“Most of the children were understanding what they were meant to be seeing. And by the time you’ve done two or three worksheets then

they've got used to the pictures and the arrows and then it's no problem for them at all."

She moreover felt that the use of the pictures made the work accessible to students who had lower attainment in English and who previously would not have understood it. However, I found it interesting that she never drew one of these pictures on the blackboard or referred to them spontaneously in her teaching.

Another characteristic of the approach is that it encourages pupils to look for similarities between different changes. Again, although Anna appreciated the existence of a few general ideas that can explain a variety of changes, I do not think she appreciated the merit of activities where pupils reason about the similarities and differences between different changes. I think that she mainly thought of them as extension work for the more able pupils. She did not stimulate discussions of that sort in the classroom.

Overall, I think that Anna provided a reasonable environment for the use of the project's materials. She did not make full use of the opportunities that the materials offered her, nor was she very imaginative and spontaneous in their use, but she used them in good faith and I believe that she enjoyed working with them.

6.4 Year 7 pupil case studies

In this section I will present in some detail the work accomplished by the six pupils selected in the Year 7 class. As already stated in section 5.6.2, these pupils were selected in consultation with the science teacher (Anna), so as to be representative of pupils of around average attainment nationally, bearing in mind the low ability intake of the school.

The accounts that will follow are based on the lesson records I kept as well as on the written assignments and tests the pupils did during the three science topics I monitored (see section 5.7.3). In these accounts no child has been given his/her real name; the choice of pseudonyms is however intended to reflect the gender and ethnicity of the pupils. The pupil answers quoted pertain to specific project's activities identified by name; in a parenthesis there is a reference to the letter and number they correspond to in the relevant publication (Boohan, 1996a), a reference to the topic under which the activity was met and a reference to the section in the thesis where the specific activity is presented. For example, the first quotation of a pupil's answer that follows refers to the activity 'Pictures of mixing' (A2, 'Water', 6.2.1.2), in other words to activity A2 in the support materials of the project (Boohan, 1996a), used in the topic 'Water', and discussed in section 6.2.1.2 of the thesis.

6.4.1 Sadiq

Sadiq was one of the pupils with the highest attainment in the Year 7 class, and of above average achievement nationally. Anna thought highly of his work (*“at level sort of seven”*) and had awarded him a certificate for best performance in science at the end of the first school term*. In the classroom he was always very active and willing to participate. His books were very neat and tidy and made a good impression as his drawings and graphs were very meticulous and his writing was of a good standard. He could express himself easily both orally and in writing; the scientific terminology did not seem to present particular difficulties for him, in his written work he used it readily and on the whole correctly.

Talking about Sadiq in her interview Anna said that at times she had thought that some of the project activities had been too easy for him.

“He would just zoom off, and I think there was only probably a couple of times where he made a mistake with the work in the whole time and he would do that by himself, I mean he’d do all the work by himself.”

However, she also believed that on the whole the activities had offered opportunities for him to think hard and to apply the new knowledge to situations of his own choice.

There is no doubt that Sadiq worked successfully with the project’s materials; he almost always used them to their full potential and in the end-of-topic tests he got high marks. However, my impression is that his performance in the interviews did not match the expectations I had for him based on his classroom performance. This, if true, could be explained by different suppositions. One says that Sadiq did not perform as well in the interviews because he did not try hard enough; he did not deem these to be important, or as important for him as his work in the classroom. Another possibility is that Sadiq was good at recognising and responding correctly to the clues present in the interactions that were taking place in a classroom, but not as good at reproducing the same response in a context which was designed so as not to suggest obvious answers.

Differences in concentration of matter

One of the objectives of the project’s materials for Year 7 is to teach pupils to pay attention to differences in concentration and to identify matter ‘spreading out’ and ‘bunching together’, ‘mixing’ and ‘un-mixing’. Sadiq did not seem on the whole to

* At the end of the first school term Anna awarded two pupils with a certificate for best performance in science and two others with a certificate for best effort in science.

have difficulties in learning these ideas. At the beginning his use of the terms was not always the intended one and occasionally showed some confusion, but by the end of the third topic he seemed to use the terms comfortably in his writing. For example, in the activity ‘Pictures of mixing’ (A2, ‘Water’, 6.2.1.2) at the start of the first topic, he used the term ‘separate’ instead of ‘spreading out’ to describe the dissolving of sugar in a cup of tea:

“If you dissolve a solid and a liquid together the outcome is that they separate and become a liquid.”

while, for the same change met again almost three months later in the activity ‘Evaporating’ (C7, ‘Air’, 6.2.2.4) he wrote:

“Nothing is evaporating here, but the sugar particles are spreading out and mixing into the water.”

These two explanations do not only differ in his choice of words; in the second one we see Sadiq accounting for the process of dissolving in particle terms, while in the first he stayed at a phenomenological level. His use of the term ‘separate’ to mean ‘spread out’ is a problem however, not only because of its ‘macroscopic’ connotations, but also because in other work of the project the term is used as synonym of ‘un-mixing’.

Sadiq also successfully used the ideas of ‘spreading out’ and ‘mixing’ in describing the behaviour of gases. Explaining the process of evaporation in relation to boiling some water in a kettle (‘Evaporating’, C7, ‘Air’, 6.2.2.4), he wrote:

“The water is becoming a gas because the water particles were hot enough to spread out and mix into the surrounding air.”

Of course he should not really say that particles ‘are hot’ but otherwise shows a rather good understanding of evaporation as a process of ‘spreading out’. Three months later this understanding was not yet very robust and/or generally applied. When Sadiq was asked to explain why a plant will wilt faster on a windy day in the activity ‘Getting out of balance’ (D3, ‘Life’, 6.2.4.2), he told me that he knew that the water would evaporate quicker on a windy day, but that he did not remember why. He, however, later explained in his book that a plant would wilt faster on a windy day *“because the wind will help the water vapour from the plant spread out quicker”*.

For the use of the terms ‘bunching together’ and ‘un-mixing’ there is not enough evidence in his books. According to Anna, the introduction of growing up as a ‘bunching together’ process made Sadiq think hard.

Spontaneity

The terms introduced to refer to the direction of a change seemed to create more problems for Sadiq. In the activity ‘Spreading out and bunching together’ (A7, ‘Water’, 6.2.1.7) he picked them out correctly among their suggested alternatives in order to describe the four changes also depicted by abstract pictures, but failed to do the same about four other changes, for which there were no prompts. This could be explained by the fact that these terms were not given enough attention or emphasis in the teaching that had preceded. However, I also got the impression from my classroom observations that Sadiq did not always think of mixing as an ‘easier forwards’ change.

Temperature differences

Another objective of the Year 7 materials is to draw pupils’ attention to existing differences in temperature and to help them identify their disappearance. This objective was covered in the activities of the topic ‘Materials’. On the whole Sadiq seemed to do well in these activities, though he was also occasionally challenged by them. In the introductory activity ‘Getting hotter and colder’ (E4, ‘Materials’, 6.2.3.3) he appears to have had no problem choosing correctly the ‘before’ and ‘after’ instances of some thermal changes with the exception of the one showing lemonade put in a vacuum flask. For this one he chose as ‘before’ the picture in which the vacuum flask and the lemonade are at the same temperature and as ‘after’ the one showing the lemonade to have cooled down. It is unclear what was the reasoning behind his choice. In the second activity on temperature differences (‘Measuring temperature’, B2, ‘Materials’, 6.2.3.4) he appeared to have no difficulty predicting in all tasks that the objects depicted would end up at the same temperature as their surroundings. However, his concept of temperature might not have been so desirable since he reasoned that between two beakers the one that has more water is hotter; in other words he viewed temperature as an extensive quantity. Finally, in the activity ‘What happens next?’ (B3, ‘Materials’, 6.2.3.5) Sadiq needed some help to see that a bottle of cold milk left in a warm room will eventually warm up practically to the temperature of the room, as the temperature of the room will not change significantly. It is interesting that three weeks later in the test which followed the ‘Air’ and ‘Materials’ topics, when he was asked to explain what happens to a hot bath when it is left for several hours he wrote:

“The water in the bath cools down and becomes the same as the room.”

but shaded the corresponding thermometers in a way that shows that both temperatures - those of the hot bath and of the room - will change and even out.

So Sadiq did identify successfully differences in temperature and did reason that these eventually disappear. But did he see that their disappearance might drive other changes, e.g. changes of state? I will cite a quote from Sadiq's performance in the same end-of-topic test, which I consider as an indicator that he might have.

For the situation 'a window next to a kettle 'misting up'' Sadiq answered the questions 'what is happening' and 'why it happens':

"The steam from the kettle is a gas and as soon as it touches the cold window it changes to a liquid. This happens because the window is colder than the steam which is touching it and becoming liquid."

In this quote one can see that Sadiq has not only identified the change of state in terms of the change in the nature of the substance involved, but that he also attributed this change to the temperature difference between that substance and its surroundings. I therefore take this explanation to show that six months into the intervention Sadiq had attained a high level of sophistication in his accounts of changes.

Use of abstract pictures

The use of abstract pictures did not present Sadiq with any special difficulties. It is worth noting that in a test where he was asked to draw his own diagram to show what is happening to the perfume when it is spilled, he chose to draw two pictures side by side, which he called 'at first' and 'later on'. In other words he chose to follow the convention introduced by the project of having two instances, a 'Before' and an 'After' to represent a change, but preferred to represent the time arrow horizontally, rather than vertically. In his pictures he (like the project's materials) represented a gas as spaced-out dots for particles, and he distinguished the perfume and air using different coloured pencils.

The pictures that seemed more problematic to him were the ones that showed air in different containers ('Air - squeezing, stretching, pushing and pulling', C1, 'Air', 6.2.2.1). These pictures required one to think about amounts, volumes and pressure of air in different situations and Sadiq had some difficulty in taking all three aspects into consideration when choosing a picture. He also showed no appreciation of the role the nature of the walls of a container plays in thinking about the pressure of the air inside the container. For Sadiq a blown up balloon and an empty can of Coke, both contained "*air particles cramped together*".

Identifying similarities and differences

Finally, Sadiq's work shows that he was capable of discerning the important features of a change and of using them to think about similarities and differences among

different changes. An example is his comparison of ‘a spoonful of sugar dissolving in a cup of tea’ with ‘pollution from a factory spreading out into the air’:

“They are the same because the sugar is dissolving in the cup of tea and is spreading out. The pollution is also mixing and spreading out into the air.

They are different because a solid is mixing into tea, but a gas is mixing and spreading out into the air.”

One can see that he identified similarities in the basic processes taking place, namely the ‘spreading out’ and ‘mixing’ of substances, and differences based on the nature of the substances involved. Both identifications are characterised by high level of generalisation.

6.4.2 Rehana

Rehana was a pupil of above average attainment in her class and of about average achievement nationally. Anna awarded her with a certificate for best effort in science at the end of the first school term. She seemed on the whole motivated and participated willingly in the classroom. Her workbook gave a good impression as her handwriting was neat and her tables and diagrams carefully drawn. She expressed herself easily both orally and in writing, although her written explanations were sometimes short and incomplete.

Rehana worked well with the project’s materials, although I got the impression that she did not always exhaust their use. While she finished some of the activities well ahead of other pupils, others appear only partly done in her book. Her performance in the classroom raised expectations on my part and in a way I think that Rehana was conscious of that. I felt that my presence and my questions to her pushed her to think harder about what she was writing. Also in the interviews she participated eagerly and with enthusiasm.

Differences in concentration of matter

Rehana’s use of ‘scientific language’ was average; she tried to use the terms she learned, forcing them sometimes in her explanations, so that she arrived at producing sentences like:

“The washing machine moves the clothes about and helps the solvent fight the dirt.”

She also had the same problem as Sadiq with the use of the term ‘separate’. At the beginning she used it both in a macroscopic and in a microscopic sense instead of ‘spreading out’. So, on the one hand she would say that “ *it is very hard to separate two liquids*” when asked to justify why to get white coffee from milk and black

coffee is an ‘easier forwards’ change, or that “*water and oil don’t mix, so they are separate*”. On the other hand she would write that “*stirring helps the solvent dissolve by separating it*”. It is worth noting that when in the later activity ‘Evaporating’ (C7, ‘Air’, 6.2.2.4) she wrote:

“...the sun is shining on the puddle and the puddle is evaporating and separating.”

about ‘a puddle drying in the sun’, she then crossed out the word ‘separating’ and wrote ‘*spreading out*’. She also, as did Sadiq, seemed to associate more readily the process of ‘spreading out’ with the behaviour of gases than with the processes of dissolving and mixing.

It is interesting to compare the explanations she gave in two activities, which pose analogous demands and which took place with almost a three-month interval between them. In the first activity ‘Dissolving - speeding it up’ (A3, ‘Water’, 6.2.1.3), writing about why using hot water to wash clothes is normally better than using cold water, (i.e. why making the solvent hotter speeds up the dissolving process), she saw dissolving solely as a splitting of a solute:

“Hot water dissolves solutes quicker than cold water because the hot water can go in the solute easier and separate it.”

Three months later, in the activity ‘Evaporation - speeding it up and slowing it down’ (C8, ‘Air’, 6.2.2.5) writing about why wet clothes dry faster if left outside on a sunny windy day, (i.e. why making the liquid hotter and keeping the air around it moving speeds up the evaporation process), she accounted for evaporation differently:

“The water will evaporate quickly outside on a sunny windy day because the heat will spread the particles out, the wind will push the water particles out and there is a lot of space for the particles to move.”

In both explanations heat (or hot water) was identified as the agent of the process. However, in the second explanation the process, i.e. evaporation, was explicitly seen as involving the spreading out of matter, and this was also expressed in particle terms. These two explanations were written with almost a three-month interval between them, during which time Rehana gained experience in using the project’s materials and terminology. This experience could somehow account for the difference in her performance.

Now, if one follows up the presence of an agent in her explanations of processes, one would be pleasantly surprised to see that for the process of diffusion she explicitly denied the existence of one. To describe what is happening to some spilled perfume she disagreed with the statements that ‘the bottle pushes the smell of the perfume

out’ and that ‘the air makes the perfume move around’, but agreed with the one that said that ‘the perfume mixes with the air in the room’. The reasons she gave respectively were:

“Because the bottle can’t push the perfume’s smell out. The perfume has to be out.”;

“The perfume moves about itself.”;

“Because there is a lot of room around so it would like to spread out as much as it can and mix with the air.”

The other term the project introduces to talk about the concentration of matter is ‘bunching together’ but this does not feature so much in her work. Unfortunately, Rehana left for Bangladesh at the beginning of the ‘Life’ topic, so we cannot see if she could manage to apply the notion of a concentration difference to living organisms.

Temperature differences

The idea that temperature differences tend to even out proved straightforward for Rehana. She was happy to reason that a hot bath would cool down to the room temperature if left for several hours, and in the case of a test tube with cold water in a beaker of hot water that *“the two different temperatures are going to mix up and even”*. However, this conviction did not seem to survive in counter-intuitive cases such as the one where fur insulation is wrapped around a beaker of water, or where the temperature of a block of wood is compared with that of a block of metal. For the first one she readily chose the picture that showed that the water will end up warmer than the insulation, and for the second one she predicted that the metal block will have a lower temperature than the wooden one (both being common misconceptions among children). When the project activity ‘Measuring temperature’ (B2, ‘Materials’, 6.2.3.4) gave Rehana the opportunity to test this latter prediction she found out that a discrepancy between what she could feel with her senses and what the thermometers showed. She explained that discrepancy to me

“You can’t feel the coldness on the wood but you can on metal. Because the wood has holes and the cold goes inside while in the metal the cold stays on the outside.”

Previously, we saw Rehana saying that the sun or the heat is responsible for evaporation. By the end of the topic ‘Materials’ however, she formulated a more complete and desirable conception about the cause of the changes of state.

“The hot sun is melting the bar of chocolate. It happens because the sun is hotter than the bar of chocolate.”

Spontaneity

The concept that processes happen more easily in one direction than in the other also did not seem to puzzle her, as one can infer from the instances in her book where she made use of the relevant ideas. In particular, she appears to have been strongly attached to the idea that *“you can’t get a substance back once it has changed”*.

Use of abstract pictures

Rehana managed on the whole to comprehend and use the abstract pictures successfully in the course of the year. The first such pictures she met were in the activity ‘Pictures of mixing’ (A2, ‘Water’, 6.2.1.2). At this early stage she made an interesting mistake. Although she chose the right picture to match the change ‘adding instant coffee to hot water’ (it showed a solid and a liquid changing to a liquid different from the first), she matched ‘dissolving sugar in a cup of tea’ to a picture which showed at first a solid in a liquid becoming just that liquid on its own, as if the solid had vanished. She justified this difference in the choice of pictures to me with the words *“because you can’t see the sugar after it is dissolved, but you see the coffee”*. The different shadings in the pictures meant different substances; Rehana seems to have interpreted them to mean different *appearances*.

The other pictures she found difficult to use were the ones showing the air pressure in different containers. As in the case of Sadiq the problem with these pictures is that in order to understand them one must take into consideration a lot of variables at the same time.

Finally, I think it is interesting to mention the diagram Rehana drew for the test she took at the end of the ‘Air’ and ‘Materials’ topics, to show what is happening to perfume when spilled in the room. It consisted of one picture showing at the same time the perfume more concentrated at one corner of the room and evenly spread out in the rest of the room. She explained that her diagram showed that the perfume was spread out and mixed with the surrounding air. The point I want to make here is that Rehana did not use the project’s convention of two pictures to show a change, but rather drew an instance of the change. This seemed carefully chosen so as not to be the final state where all the perfume is evenly spread in the room, but near enough to it to contain both static and dynamic features. The concentrated perfume in one corner of the room shows something of the initial state (or ‘Before’ in the project’s terms), while the evenly spread out perfume in the rest of the room points to the final state (or ‘After’). I read this picture as showing that Rehana had become aware that a picture of a process of change should show more than just one state of affairs.

Moreover, I am prepared to suppose that this awareness was acquired through her exposure to the project's materials.

Identifying similarities and differences

Finally, in drawing similarities and differences between different changes Rehana right from the beginning of the teaching sequence, when supported by pictorial representations, attained a high level of generalisation. Comparing the changes 'copper sulphate crystals forming when a hot solution is cooled' and 'sugar crystals forming in a pot of honey when it is left for a long time', after having matched them to the same abstract picture in the activity 'Pictures of separating' (A6, 'Water', 6.2.1.5), she wrote:

"They both had a solution. The solid was taken out but some of it was left behind. So there is a solid and a solution."

She successfully identified the initial and final instances of the changes in terms of the nature of the substances involved, and described the process at a general level.

6.4.3 Teresa

Anna regarded Teresa as a pupil of above average attainment and awarded her with a certificate for best performance in science at the end of the first school term. She was lively, but her interest in participating in the classroom activities varied. She had a very good attendance record and usually completed the work that was asked of her, though rarely did any extension work. I had the impression that she did not work as hard as she could; there were times that she seemed bored and unmotivated. Also, I occasionally felt that she resented my questions, especially when she had to think hard in order to answer. Her book was neat and well kept, though her spelling was poor. Moreover, her written English was not of a very good standard and thus her explanations were not always very extended or clear.

On the whole she worked well with the project's materials. It is hard to say what she felt about her participation in the interviews I conducted. Sometimes I thought she was indifferent to them, but on an occasion when a whole interview was not recorded she volunteered, and persuaded the rest of the pupils in her group, to repeat a part of it.

Differences in concentration of matter

It is difficult to say whether Teresa internalised the ideas conveyed by the project's materials concerning differences in concentration of matter. Whenever in an activity the terms 'spreading out' or 'bunching together' were given to her, she could pick them out correctly, but rarely used them in her own explanations. Did she see

‘dissolving’ as a ‘spreading out’ process? It is hard to tell. When she wrote about the factors that make things dissolve faster, in the activity ‘Dissolving - speeding it up’ (A3, ‘Water’, 6.2.1.3), she seemed to give more importance to the action of the solvent on the solute, than to what is happening to the solute itself. For ‘using more liquid’, for example, despite the suggestion offered on the worksheet that it speeds up the process because it gives the solid more room to spread out, she wrote:

“In this one there are more [water] particles, so it can dissolve the sugar faster.”

What about evaporation? In her answer to the question whether some washing would dry quickly or slowly if left on a radiator next to an open window, she identified the elements that she thought make something dry quickly, but did not explain what their effect is:

“If it’s on a radiator next to an open window it will dry quickly because there is lot of air, there is heat, and there is wind on it.”

And in the same way she answered the rest of these questions, which were designed to prompt pupils to use the idea of ‘spreading out’ in connection with the process of evaporation (see ‘Evaporation - speeding it up and slowing it down’, C8, ‘Air’, 6.2.2.5). However, three and a half months later at the test at the end of the topic ‘Life’, we find Teresa writing that *“water gets out of the plant by evaporation”*, and closely after that *“if the water is evaporating the water is spreading out into the air”*, a clear declarative statement that dispels any doubts that she had made that connection.

In the same test she showed that she could also apply these ideas of concentration differences to living organisms. When asked if, when water gets into a plant, the water is ‘spreading out’ or ‘bunching together’, she answered that it is bunching together and explained:

“When things grow, the stuff inside them bunch together.”

In further questions, she gave the examples of ‘a man eating his dinner’ and ‘a plant dying’, as examples of substances ‘bunching together’ and ‘spreading out’ respectively.

Temperature differences

The activities concerning temperature differences presented some difficulties to Teresa. Her pattern of responses in the activity ‘Getting hotter and colder’ (E4, ‘Materials’, 6.2.3.3) shows that she failed to grasp its purpose; she always picked as the picture to come second the one where the depicted system ended up warmer than before, even if that meant that it ended up warmer than its surroundings. For example

for a pair of pictures with one (picture A) showing a test tube with water at 35°C inside a beaker with water also at 35°C, and the other (picture B) showing a test tube with water at 80°C inside a beaker with water at 20°C she reasoned that picture A would come first in the sequence of events. Furthermore, in the activity that followed ('Measuring temperature', B2, 'Materials', 6.2.3.4), where children got the opportunity to put some of their conceptions about temperature to the test, and which features only partly finished in Teresa's book, we see her predicting that a beaker full of hot water would have a higher temperature than that which is only half-full of hot water, simply *"because there is more water in it"*. This view of temperature as an extensive quantity has been reported by science educators as a common misconception children have. Finally, Teresa also thought that a cold metal block put into hot water would always remain a little bit colder than the hot water. This misconception, which is again common to many children, surfaced in the context of the project's activity 'What happens next?' (B3, 'Materials', 6.2.3.5).

Identifying the changes of state as well as the changes in the nature of substances they involve did not prove difficult for Teresa, although she did not always pick the scientific terms to describe them, especially the ones that appear less often in everyday language, such as 'freezing' and 'condensation'. In explaining these changes she showed awareness that a temperature difference or a temperature change plays a role in them, but did not arrive at expressing that very clearly. For the change 'chocolate left in the Sun' she wrote in the 'Air and Materials' test:

"It happens because the sun is too hot for the chocolate."

and for the change 'lava from a volcano turning into solid':

"This happens because the lava is getting cold and turning back into a solid."

Spontaneity

The use of multiple terms to talk about the direction of change did not seem to create any problems for Teresa; she clearly had established their internal consistency, that is which were equivalent expressions. However, her use of them was not the intended one. In the activity 'Spreading out and bunching together' (A7, 'Water', 6.2.1.7) she was asked to write about what is happening in four given changes in her own words. Teresa, imitating the examples suggested to her in the first part of the activity attempted to make use of the expressions 'just happens/does not just happen', 'downhill/uphill', 'easier forwards/easier backwards' in writing about these changes. So, for her 'adding a mixture of salt and sand to water', 'copper sulphate crystals forming as a hot solution cools down' and 'hard water evaporating leaving behind a solid' are all 'downhill' changes, while 'removing water from milk to make milk

powder in a factory' is an 'uphill' change. It is interesting to note that while she correctly judged what is happening to the parts in each change, that is if each of the substances is 'spreading out' or 'bunching together', mixing or separating, she appears to have based her decision on whether a process is 'uphill' or 'downhill' on the presence or not of obvious human intervention. What was intended by the activity was for her to reason that processes of separating are 'uphill' changes, whereas processes of mixing are 'downhill' changes.

Use of abstract pictures

There is substantial evidence that on the whole Teresa made sense of the conventions used in the pictures. It is interesting from the point of view of the project that on the whole when she described what the pictures represented she referred to a process and not only to the 'before' and 'after' instances depicted in the picture. For example, she wrote

"This is a picture of two liquids mixing into one to make a liquid solution."

for the relevant picture.

The pictures of air pressure presented the same problems to her as to the rest of the pupils. When she drew her own picture to show what happens to a blown-up balloon when one lets the air out, she tried to use the conventions suggested in the activity and thus showed that it had not been obvious to her that the pictures included information about the size of the container (or the volume of the air), as well as about the density of the air in it. Furthermore, the pictures she drew to show what happens to air freshener when it is sprayed in the middle of a room give the impression that she failed to conserve the amount of gas which spreads out. In other words we see the air freshener extending in space and mixing with the air, but it does so increasing in concentration.

Identifying similarities and differences

Finally, a point about Teresa's response to the problem of reflecting on similarities and differences between two changes. Unfortunately, the only such occasion in her book appears relatively near the start of the teaching sequence in the activity 'Pictures of separating' (A6, 'Water', 6.2.1.5), so I cannot examine if there is any development in the quality of her arguments after more extensive use of the materials. Explaining what is similar between 'separating peas from boiling water after cooking them' and 'filtering water through gravel beds in a waterworks to remove solids' - changes that she had matched to the same abstract picture - Teresa started by describing the abstract picture:

“This one is about a solid and a liquid together then separated.”

and continued to write:

“Both of them have a solid and a liquid in them.”

What we see here is that she drew similarities based on the nature of the constituent parts of the changes, and - unlike Rehana - not on the process they have in common. While I regard this reasoning as showing that Teresa had attained some level of generalisation, I also find it incomplete and unsatisfactory. It is unfortunate that we do not have examples from her later work.

6.4.4 Dionne

Dionne was a pupil of below average attainment nationally. In the classroom I remember him as being withdrawn and rather disinterested. Sometimes he seemed frustrated and bored, especially when there were things he said he could not understand. His book was neat and well kept although there is a lot of half-finished work in it. His written English was also not very fluent; his spelling was poor, and the explanations he gave were rather brief, incomplete, and occasionally unclear.

It is hard to say how Dionne worked with the project's activities. Although some activities were not fully written up in his book, it was usually only the extension work which was missing. Having said that however, it is with this extension work that in many activities pupils are prompted to reflect upon what they learned and either apply it to more unfamiliar situations or relate it to knowledge already acquired elsewhere. Furthermore, unfortunately Dionne changed school at the beginning of the last topic 'Life', so he did not do the latest activities which introduced the idea of concentration differences in living organisms, and consequently did not participate - together with Rehana and Sadiq who had left on holiday - in the last of the group interviews.

For the purpose of my study Dionne was paired to work with Rehana. When Anna changed his seat in order to render this possible, he objected strongly. In the course of the year there were no signs of friction between him and Rehana; however, apart from the activities that explicitly required team-work, Dionne worked mainly on his own, interacting only minimally with Rehana.

Differences in concentration of matter

Dionne did not always use the terms 'spreading out' and 'bunching together' correctly; however he did make use of them when he was prompted to do so and sometimes even when he was not. Moreover his use of them seems to have become

more sophisticated with the passage of time. So, when he first attempted to use the idea of ‘spreading out’ to explain why ‘soap powder dissolves quicker than a bar of soap’ he wrote:

“When you have some soap powder which has been crushed and you put it in water it will spread out faster because the soap is spread out already.”

Two and a half months later, he would explain why wet washing would dry faster outside on a sunny windy day, as follows:

“Your clothes will dry because the particles would want to come of your clothes because it is going to be a sunny day and the wind would want to push away the particles and there would be space to spread out.”

In the second explanation we see Dionne attempting to reason in terms of the particles spreading out, an expressed acknowledgement that the term describes microscopically what is happening to matter. It is a shame that we cannot see if and how he would use the same term for concentration differences in living things.

The terms ‘spreading out’ and ‘bunching together’ did not work very well for Dionne when applied to describe changes of mixing and separating. In the activity ‘Spreading out and bunching together’ (A7, ‘Water’, 6.2.1.7) which took place at the end of the first topic one finds Dionne confused in his choice of them. So, while in his account of the change ‘adding a mixture of salt and sand to water’ he wrote that *“salt is spreading out into the water and sand is bunching together”*, he wrote that *“nothing is ‘bunching together’”* for the change ‘hard water evaporating leaving behind a solid’. In that lesson the term ‘bunching together’ was introduced for the first time, and it might be that Dionne was not very clear about what it meant.

Temperature differences

The activities about temperature differences were not so straightforward for Dionne. In the activity ‘Getting hotter and colder’ (E4, ‘Materials’, 6.2.3.3) he expressed the same misconception as Rehana and Teresa, namely that the fur around a beaker of water would heat the water up, and in the one that followed - ‘Measuring temperature’ (B2, ‘Materials’, 6.2.3.4) - he predicted - just as Rehana and Teresa - that a metal block would have a lower temperature than a wooden one in the same room. What I find worth mentioning however is how his predictions / explanations of what would happen to a test tube with cold water when put into a beaker with hot water varied across his work. In the ‘Getting hotter and colder’ activity he wrote:

“Water from the inside cools down the water which is in on the outside.”

Accordingly, in the ‘Measuring temperature’ activity he chose - among the suggested ones - the prediction:

“They will both end up at the same temperature.”

However, three weeks later, in the test at the end of the topic he wrote for the same situation:

“The hot water will make the cold water much warmer, but the hot water will still be hotter.”

This explanation becomes even more unaccountable because it followed one about a hot bath left in a room for several hours which said:

“In the first [picture] the bath is hot and the room temperature is cool, but in the second the bath comes down to the room temperature.”

and which I consider well developed and successful.

While from one only example one cannot say very much, it is maybe reasonable to assume that Dionne did not hold very firmly the idea that temperature differences tend to even out.

In Dionne’s accounts of changes of state we see that he identified temperature differences as their causes and that he used the names of the processes correctly. However the change in the nature of the substances was not always identified correctly.

Spontaneity

About his understanding and use of the terms that refer to the direction of change, the evidence again is scarce. In the activity ‘Spreading out and bunching together’ (A7, ‘Water’, 6.2.1.7) he picked them out correctly when they were offered to him as alternatives for the description of four changes of mixing and separating, but he did not make use of them when he wrote his own descriptions of another four changes. From my observation records I know that Dionne had some problems with the ‘easier forwards’ / ‘easier backwards’ expressions; he kept thinking of ‘forwards’ as ‘upwards’ and ‘backwards’ as ‘downwards’. In the test at the end of the topic ‘Water’ when asked if soapy water becoming washing-up liquid and water is easier forwards or backwards, he wrongly answered with ‘forwards’. Furthermore, when in the ‘Wearing out’ activity (F2, ‘Materials’, 6.2.3.2) he was asked to think whether it would be easy (or difficult) to reverse some changes and get either the object to the way it was at the start, or the substance there was at the start, he narrowly reflected only on the practicality of the procedure for each change to answer. He failed thus to generalise that changes where the substance turns to a different substance are more

difficult to reverse than those where the object changes, but the substance stays the same.

Use of abstract pictures

The use of abstract pictures did not seem to present difficulties on the whole for Dionne with the exception of the pictures showing air at different air pressures in different containers (as was also the case with the other pupils). However, in his first encounter with them in the ‘Pictures of mixing’ activity he felt overwhelmed by them; he told me that he was bored because he could not understand the pictures. I spent some time explaining the conventions to him which he seemed eventually to grasp. In the lessons that followed he never complained again.

His drawing of perfume spreading out from a bottle has the characteristics of Rehana’s picture with the exception that it shows only one kind of particle spreading out. This is consistent with his description that:

“The air will get into the perfume bottle and mix. Then the air will come out with the perfume and spread out.”

On a previous occasion when he had drawn three pictures to show air freshener spreading out in the room I confronted him with the fact that in his last picture one could see only the air freshener, but not the air. He replied that this was because the air was carrying the air freshener.

Identifying similarities and differences

About Dionne’s ability to draw similarities and differences between two changes the evidence comes mainly from the activity ‘Pictures of separating’ (A6, ‘Water’, 6.2.1.5) which featured in the first month of the observed teaching. An example of an answer he gave at this stage, about how ‘evaporating hard water leaving a solid behind’ and ‘making salt by leaving sea water to be heated by the sun’ are similar, is:

“They are making the water evaporate by heat.”

In other words although he identified a common process for both changes at a general level, his answer did not capture the whole essence of the two changes in which a solution is un-mixed into a solid and some vapour by the process of evaporation.

The reason he gave, however, for grouping ‘hot soup put into a freezer’, ‘lava from a volcano turning solid’ and ‘ice forming on a lake’ in the activity ‘Putting changes into groups’ (C5, ‘Materials’, 6.2.3.6) four months later was:

“These are freezing because your substance is hot and is being put into a cold place.”

I think this shows that in that case he was better able to express the common process that describes the three changes, both by naming it and giving a cause for it in terms of a temperature contrast. This was one of the last activities Dionne did before he left the school.

6.4.5 Imtiaz

Imtiaz was also one of the high attainment pupils of the class. He was paired to work with Sadiq and this I think benefited both as in attempts to outperform each other they often mutually challenged their ideas. Imtiaz was a lively pupil, always eager to contribute in the classroom. He expressed himself with ease both orally and in writing, and kept his book well organised. He overall worked well with the project's activities, most of which appear complete in his book and some even extended. His attendance was good and he participated in all four interviews.

Differences in concentration of matter

From the terms introduced by the project to refer to changes in the concentration of matter, the term 'bunching together' seems to have created most difficulties for Imtiaz. We see him using it for the first time to describe what is happening when a mixture of salt and sand is added to water. "*Salt and sand and water are bunching together*", he wrote when he had previously also written that "*salt and sand are mixing with water*". It is worth mentioning that the same mistake appears also in Sadiq's account of the change. Moreover, half a month later, in the 'Gases: Spreading out and mixing' (C3, 'Air', 6.2.2.3) activity, in describing what happens to air freshener when sprayed in the middle of a room and to carbon dioxide when put into a large container, he, on the one hand suggested that they are spreading out and mixing with the air, and on the other that in the end instance each substance and the air are bunching together. I presume that he used the term with a different meaning than that attributed to it by the project, so that the ideas were not contradictory. What this meaning was however, I cannot tell. We see Imtiaz using the term again in the last topic - 'Life' - in relation to living organisms. His use of the term in that context is the intended one and - I think - shows that Imtiaz managed to express quite sophisticated ideas with it. In the test at the end of the topic 'Life' when he was asked to write his own example of substances 'bunching together' and to explain what happens in it, he wrote:

"A baby's hands grow. The food the baby eats go into the bones and bunch together."

The term 'spreading out' is used by him skilfully right from the beginning. He shows a clear understanding that both dissolving and evaporation involve the spreading out

of a substance and thus that speeding up these processes involves facilitating this spreading out. So, for why it is better to use a lot of water to clean a paint brush he wrote:

“[...] As there’s more water there’s more room to spread out.”

and for why wet washing will dry faster on a radiator next to an open window he wrote:

“On a radiator next to an open window it will evaporate quickly because there’s lots of air for the particles to spread out in and the heat will help the particles spread out.”

The second explanation appears two and a half months after the first one; in this time Imtiaz seems to have moved to an account of ‘spreading out’ in particle terms. This move, although it is desirable, can not be attributed to the use of the project’s materials as they did not include particle descriptions at this stage. It is more due to Anna’s prompting and insistence on using them in the accounts of dissolving and evaporation processes. However, this explicit mention of particles is not maintained in Imtiaz’s explanations of concentration changes in living organisms even when these are only caused by evaporation. Furthermore, when the process of the change was not understood very well, as in the case of decay, Imtiaz oscillated between a macroscopic and a microscopic use of the term ‘spreading out’. For the change ‘leaves fall from a tree and decay’ he wrote:

“Spreads out, because as the leaves fall they spread out.”

interpreting the term clearly only macroscopically, while for the change ‘a fish dies and decays’ he wrote:

“It spreads out because the things from the inside of the fish spread out into the sea.”

an account which - I think - hints of an awareness that the ‘spreading out’ process is happening also microscopically.

Temperature differences

In the first activity on temperature differences (‘Getting hotter and colder’, E4, ‘Materials’, 6.2.3.3) Imtiaz performed rather poorly. Not only did he reason like the other pupils that fur round a beaker of water would cause the water to warm up but also that lemonade in a vacuum flask (see also Sadiq’s case study) and a metal block in air, both being at equilibrium, would cool down by themselves. These misconceptions however, must not have been rooted very deeply and/or were not applied very consistently, because they cannot be traced in any of the following activities. Already in the second activity on temperature differences, when Imtiaz was explicitly asked to consider whether water in a beaker with loft insulation round

it and water in a beaker with no insulation would both be at the same temperature, or whether the one with loft insulation would get warmer, he without difficulty reasoned that *“they’ll eventually be the same temperature”*. He reasoned similarly in all appropriate cases.

Imtiaz, however, saw the disappearance of temperature differences as always being expressed by both an increase (or a decrease) in the system’s temperature and a decrease (or an increase) in the surrounding’s temperature, independently of the size of the surroundings. So in the test at the end of the topics ‘Air’ and ‘Materials’ when he was asked to explain what happens to the temperature of a hot bath which is left for several hours in a room which is at a lower temperature, he wrote:

“The heat mixes with the air, so the air gets warmer and they become the same.”

The same thing - he wrote - happens to cold water in a test tube when this is put into a beaker with hot water, namely it gets warmer. It is interesting that in both explanations he paid attention to the ‘thing’ that gets warmer. I also find it important that he identified an action - heat mixing with the air - as the cause of this temperature change and not heat itself. This identification, also present in other written explanations of Imtiaz, I consider as being a precursor of the conceptualisation that temperature changes involve energy flows.

In writing about changes of state Imtiaz did not always acknowledge the presence of a temperature difference as their cause. His accounts of them almost always included the scientific names of the processes and were mainly in terms of the changes in the nature of the substances involved. For example, for grouping ‘ice forming on a lake’, ‘lava from a volcano turning solid’ ‘hot soup put into a freezer’ together he wrote:

“This is classified as freezing, because a liquid is becoming a solid. Liquid to solid.”

This account appeared in the ‘Putting changes into groups’ activity (C5, ‘Materials’, 6.2.3.6), which was intended to be done before changes of state were explicitly taught as such. So, although Anna had mentioned them at the beginning of the ‘Water’ topic - five months prior to the above activity - and had introduced them in terms of the changes in the nature of the substances they described, the pupils had not met any other of the project’s activities about changes of state prior to that one. The project’s activities that followed explicitly put emphasis on the temperature difference which makes each change of state happen. Imtiaz after having being exposed to them wrote about ‘lava from a volcano turning solid’:

“Freezing. The hot lava cools down. So it becomes a solid.”

The second explanation is by no means complete. It however describes the change in a more complex way than the previous one as it identifies a temperature change as well as a change in the nature of the substance.

Spontaneity

Imtiaz seemed to have no problem with the expressions that the project used to talk about the direction of change. In the few occasions where we see him having used them, he used them correctly although never spontaneously. Furthermore, in the activity ‘Wearing out’ (F2, ‘Materials’, 6.2.3.2) Imtiaz, unlike Dionne, explicitly drew the conclusion that

“If an object changes you can get back very easily but if the substance changes it is very hard.”

Use of abstract pictures

The use of abstract pictures in the activities did not present any difficulty for Imtiaz either. Even those used to show air in different containers and at different pressures proved less problematic for him than for most of the other pupils. While his explanations in the activity ‘Air - squeezing, stretching, pushing and pulling’ (C1, ‘Air’, 6.2.2.1) show that he too did not fully understand what these abstract pictures were meant to represent, he correctly managed to identify the ones that corresponded to the four suggested changes in the activity. He, moreover, made use of their conventions successfully in the picture he drew in the same activity to show the change ‘letting the air out of a blown-up balloon’.

Identifying similarities and differences

In drawing similarities among different changes Imtiaz showed that he was capable of abstracting the essential features of the changes. However, while the similarities he identified were at a general level, he was easily content with identifying one kind of similarity and thus his answers often appear incomplete as in the above example of the justification he gave for grouping three changes as ‘freezing’.

6.4.6 Tamba

Tamba was a pupil of below average achievement nationally. He was paired to work with Teresa with whom he collaborated on the whole successfully. He was a very lively pupil and was eager to participate in the classroom discussions. However he did not always concentrate on work, spending time talking to and teasing other pupils. His book is very presentable as it is tidy and his work is well organised. His written English flows nicely and could be called fluent if it were not that his

sentences occasionally have missing words or contain repeated words or expressions. This I attribute to his being easily distracted from what he was doing.

Tamba worked well with the project's materials. Although some of the activities appear unfinished in his book, he completed the great part of them and even did some extension work for a few. He was a pupil who held his ideas firmly and was not easily shaken from them. Several times I noticed that even after explaining to him what the right answer was, he would still write what he originally thought was right.

Differences in concentration of matter

What he seems to have understood by the terms 'spreading out' and 'bunching together' is shown by his description of concentration changes in living organisms. In the test at the end of the last topic 'Life' Tamba was asked to say whether he thought that substances are 'spreading out' or 'bunching together' as a kitten grows into a cat; he wrote:

"It's bunching together. When a cat grow, its bones, skin and muscles stay together and don't go in any other direction."

In an activity shortly preceding the test he also wrote about the change 'leaves fall from a tree and decay':

"When leaves fall off a tree they spread out because the wind blow them to all different directions."

In both accounts we see him having used the terms in their everyday meanings but suitably adapted to the requirements of the activity. Whereas he was clearly thinking about what was happening to macroscopic pieces of matter, and not what might have been happening to the particles, he came up with the right term for each change. He got the 'right answers' but for the wrong reasons. However, when he wrote about processes, such as dissolving or evaporation, that he understood better, his use of the terms, although still rare, seems to be closer to what was hoped for. So, for wet washing on a radiator next to an open window he wrote:

"If it's on a radiator next to an open window it will evaporate quickly because the radiator and the wind help the particles spread out quickly."

What is interesting is that Tamba felt happy to apply the above ideas about evaporation in reasoning about a plant wilting three months later:

"A plant wilts on a windy day because the wind makes the water from the plant evaporate quicker."

but not in reasoning about whether we feel thirsty on a still day:

“We feel thirsty on a still day because there’s no wind to cool us down.”

It seems clear that the second explanation was informed by Tamba’s personal experience and not by his knowledge of the factors that affect the rate of evaporation.

Temperature differences

In the activities concerning temperature differences Tamba performed on the whole like the other pupils. In the activity ‘Getting hotter and colder’ (E4, ‘Materials’, 6.2.3.3) he gave exactly the same wrong answers as Imtiaz, which could imply that either they worked them out together, or that neither of them paid much attention when doing this activity. We need to take into account that the activity was administered in the classroom by a supply teacher as Anna was absent that day. His performance in the activity ‘What happens next?’ (B3, ‘Materials’, 6.2.3.5) was also not satisfactory. In this he had to choose the picture that he thought best showed what would eventually happen to the temperatures of the system and its surroundings in six spontaneous changes. While for five of the changes he picked a picture showing the system and its surroundings ending up at the same temperature, only for two did he pick the right picture. However, as he did not write any explanation for any of his choices it is hard to tell whether these were the products of misconceptions or of his bad understanding of the conventions of the pictures. In the test however that followed the topics ‘Air’ and ‘Materials’ we see him explaining that a hot bath left for several hours will *“cool down to the room temperature”*, and also that cold water in a test tube will *“warm up to become the temperature of the hot water”* of the beaker that surrounds it. Whether he saw this disappearance of temperature differences as driving the changes of state is not very clear. In the same test his answers to the question ‘why it happens’ applied to each of three changes of state varied between a quite superficial one about the change ‘chocolate left in the Sun’:

“It happens because the chocolate has been left out in the sun for too long.”

and a quite sophisticated one about the change ‘lava from a volcano turning solid’:

“It happens because the lava cools down to the air temperature around it.”

Spontaneity

Of Tamba’s use of the terms that signal the direction of spontaneous change interesting evidence is found only in his work for the ‘Spreading out and bunching together’ activity (A7, ‘Water’, 6.2.1.7). There he was prompted to apply them in the description of four changes; he used them only in two. From this little evidence, but also from other scattered evidence that appears in activities which required him to

pick the right terms among their alternatives, it seems that on the whole Tamba used all alternative expressions correctly with the exception of ‘easier forwards’ / ‘easier backwards’ which he occasionally confounded. Moreover, from what he wrote in the ‘Wearing out’ activity (F2, ‘Materials’, 6.2.3.2) it looks that, unlike Imtiaz, he did not arrive at the conclusion that changes in the substance of an object are more difficult to reverse than changes where the substance stays the same.

Use of abstract pictures

The use of abstract pictures does not seem to have presented any special difficulties for Tamba. With the exception of the pictures that represented air in different containers at different pressures which proved confusing for him, the rest succeeded in prompting him to generalisations like the following, even on his first encounter with them. For the change ‘adding sand to water’ he wrote:

“The solvent and the solute mix together but the solute doesn’t dissolve.”

Identifying similarities and differences

The pictures also helped him to think about similarities between different changes. When asked to compare the changes ‘getting fresh water by distilling sea water’ and ‘distilling copper sulphate solution to get pure water and copper sulphate’ after having matched them to the same abstract picture, he wrote:

“In these two examples water is being separated from a solid and you get two separate things.”

Unsupported by pictures, in the activity ‘Putting changes into groups’ (C5, ‘Materials’, 6.2.3.6) almost four months later, the similarities he drew were limited to naming the process or processes which were common among the changes.

“In this group the process of melting is taking place.”

was what he wrote for a group of four changes which included ‘an ice cream on a hot day’, ‘a snowman on a warm day’, ‘butter in a hot frying pan’ and ‘chocolate left in the sun’. Of course he made a desirable generalisation, but his account is much more limited than those he gave when matching processes to pictures of what was going on in them.

6.4.7 Summary

The above accounts follow the progress of six Year 7 pupils over the course of some eight months. In particular, we see how these pupils responded to the novelties introduced by the ‘Energy and Change’ project’s curriculum materials used in their science lessons. As might be expected no pupil responded only positively, or only

negatively to the approach. Although there were more than a few cases where the pupils seemed not to be able to make full use of the project's ideas, the dominant impression I was left with was that all the pupils on the whole worked successfully with the activities; they made use of the suggested terms and made sense of the various pictures of kinds of processes. Furthermore, with the aid of the pictures they seemed to achieve a higher level of generalisation - that is, ability to see different changes as sharing essential features - in their explanations of physical, chemical and biological change than they did without them.

These findings are used in the discussion of the conclusions for Year 7 (section 7.6), as well as in the discussion of the overall conclusions of the study in chapter 11.

CHAPTER 7

Year 7 Interviews with Pupils

7.1 Introduction

This chapter contains the analysis of the Year 7 interviews with pupils. Four interviews took place throughout the intervention (see section 5.6.1) and each of these was repeated with at least four groups of Year 7 pupils. These interviews were analysed from a variety of perspectives, focusing on specific tasks and on pupils' progress in them across time.

The last section of the chapter (section 7.6) draws on all the findings concerning the Year 7 pupils from Chapters 6 and 7 in an attempt to conclude on whether the pupils showed any progress with respect to the specific objectives that the intervention had set for them.

7.2 'Grouping' task: Comparison of all Year 7 first (A) and last (D) interviews

This analysis is looking at the kinds of similarities (and differences) the Year 7 pupils identified as part of the 'grouping' (first) interview task. It further examines whether these changed as a result of the intervention, by comparing the first with the last set of interviews for this task (for more details about the rationale of this analysis see subsection 5.7.4.1).

7.2.1 Description of 'grouping' task in first (A) and last (D) interviews

In the 'grouping' (first) task of the A interview the pupils were presented with twelve situations while in the same task of the D interview they were presented with eight situations (for details about the design of this task see section 5.6.1). The A interviews were conducted before any teaching using the project's materials took place, and included a variety of changes. These were:

- scent or after-shave evaporating from the skin
- *ice forming on a pond*
- a cold drink left out in the sun
- *acid rain eroding a stone statue*
- hot lava from a volcano turns solid
- making soup out of powder soup and water

- fruit drying in the sun
- *a plant growing*
- a car windscreen being shattered
- *wood burning*
- digesting food
- *a hot bath cools down*

The D interviews on the other hand were conducted after the end of the third topic, which for Year 7 was ‘Life’, and included situations more closely related to that topic. In the order that they were placed on the poster paper these were:

- *a plant growing*
- running and using up food
- *ice forming on a pond*
- sweating to stay cool
- *wood burning*
- *acid rain eroding a stone statue*
- your body making extra fat
- *a hot bath cools down*

The situations that were common to both sets of interviews appear in italics. Two tables for each of these two sets of interviews can be found in the Appendix (appendices 7.1, 7.2, 7.3, 7.4). (One table shows with the aid of arrows the matches each group of pupils made. The start of an arrow is meant to show - where that was applicable - the situation of prime focus. The second table is a matrix of all possible combinations of the situations showing which of them were chosen by each of the pupils’ groups.) It is important to note that in the D interviews only four groups of pupils were interviewed compared with five groups in the A (and the other) interviews. The reason for this was that three students - Sadiq, Rehana and Dionne - had left the school at the time the D interviews took place. This was quite unfortunate, both because these pupils were the subjects of three of my case studies, which means that their performance in the final interview was of special interest, and because as a result of their leaving the composition of the groups changed, making the direct comparison of one group’s performance across the two interviews problematic.

7.2.2 Pupils identifying similarities

7.2.2.1 Kinds of groupings suggested in the first and last interviews

The kinds of groupings suggested by the Year 7 pupils in the first (A) and last (D) sets of interviews were coded as ‘arbitrary’, ‘script’, ‘opposites’, ‘similarities’ and

‘no reason’/‘unclear’ according to the criteria discussed in subsection 5.7.4.2. The relative frequencies for these categories in the first and last sets of interviews were then calculated (see Table 7.1).

YEAR 7 INTERVIEWS ‘GROUPING TASK’	‘Similarities’ ‘Opposites’	Script	Arbitrary	No reason Unclear
A Interviews (n= 89)	53%	8%	22%	17%
D Interviews (n= 31)	85%	3%	6%	6%

Table 7.1 Kinds of groupings suggested in the Year 7 A and D interviews

Comparing these frequencies for the categories ‘similarities’ and ‘opposites’ in the A and D interviews shows that in the D interviews 85% of the total specified units were thought to be ‘similarities’ and ‘opposites’, while in the A interviews this was the case for only 53% of them. It is furthermore interesting that in the A interviews for 22% of the attempted groupings the justifications given were thought to be ‘arbitrary’ constructions - these dropped to 6% in the D interviews - while for another 17% of the attempts either no explanation or an unclear one was offered. The corresponding frequency dropped again to 6% in the D interviews. These differences in the first instance suggest that by the fourth interview the pupils were more able to carry out the task that was asked of them; they seemed to be able to focus more on the given changes and not to drift as much to imagined associated changes. Moreover, the considerable number of ‘unjustified’ grouping suggestions in the A interviews suggests either that all situations seemed sufficiently remote to the pupils, or that the pupils applied no special criteria when they looked for possible groupings, resulting in random suggestions for groupings, with no reasons given.

7.2.2.2 ‘Similarities’ and ‘opposites’ in the first and last interviews

The comparison of the A interviews with the D interviews with reference to the kinds of ‘similarities’ and ‘opposites’ that the pupils were found as reporting shows that whereas in the A interviews 46% of the similarities and differences identified were between the participating objects and their properties rather than between the changes themselves, in the D interviews these were only 4% (see Table 7.2). That is, 96% of the identified similarities in the D interviews concerned the changes that were seen as being relevant to the situations presented to the pupils. This is considered as a positive shift as it suggests that by the fourth interview the pupils did not only consider more readily the given situations - as previously established - but also focused more on what was happening in the changes, rather than on the objects

participating in them. This assertion is even more strengthened by the fact that the frequency of ‘actual’ similarities, as opposed to ‘potential’ ones, rose from 73% in the A interviews to 93% in the D interviews (Table 7.2). Again it seems that in the last interview the pupils were able to reason more successfully about features more closely relevant to the given changes.

YEAR 7 INTERVIEWS ‘GROUPING TASK’	‘SIMILARITIES’ AND ‘OPPOSITES’		‘SIMILARITIES’ AND ‘OPPOSITES’	
	Between Objects and Properties	Between Changes	Actual	Potential
A Interviews (<i>n</i> = 45)	46%	54%	73%	27%
D Interviews (<i>n</i> = 26)	4%	96%	93%	7%

Table 7.2 *Kinds of ‘similarities’ and ‘opposites’ in the Year 7 A and D interviews*

In the following excerpt from one of the D interviews we can see the pupils rejecting the suggested similarity after explicitly arguing that it concerned a process only ‘potentially’ relevant to one of the given changes. These were: ‘a hot bath cools down’ and ‘wood burning’.

P: “They are both hot but they are going to cool down. When the fire is out, the wood is going to cool down.”

P: “No - but it doesn’t say that, does it? That says ‘wood burning’, and that says ‘a bath cools down’.”

P: “I know, but he is making it up, he’s making the thing, his own thing.”

P: “No, but look. That’s talking about the wood burning and that one is talking about the bath cooling down.”

P: “But they are both going to cool down.”

P: “Yeah, I know, but you are just talking about the future of that one.”

P: “Yeah. How do you know that it is going to cool down? You could just keep it on, [...]”

P: “I’m just saying if nobody puts no more wood in there.”

It needs to be said however, that this positive shift of focus from the objects to the processes was not followed by a similar shift towards more desirable - from the project’s perspective - similarities. In other words, while there were far more similarities of processes / events in the D than in the A interviews, the percentage of similarities, which referred to a physical or chemical change, directly or indirectly, or which acknowledged a change in the temperature or in the physical state of the objects involved, stayed almost unchanged between the two sets of interviews. This confirmed the conjecture expressed in the rationale of the analysis (see subsection

5.7.4.1), namely, that effects of that sort would be unrealistic to expect to find in quantity.

As to the category ‘human use’, whereas my original impression having read the transcripts was that there were few instances that belonged to this category, it turned out that only two ‘similarities’ came under it, one in the A and one in the D interviews; human intervention was more prominent in the ‘arbitrary’ justifications and the ‘scripts’.

7.2.3 Pupils’ spontaneous accounts of changes

I also looked in more depth at how the pupils reasoned spontaneously about each of the changes when they compared them (see subsection 5.7.4.3). I found out that, in accordance with the previous results, in the A interviews compared with the D the pupils reasoned much more about the entities present in the situations - what they are, or what they are made of - and about what they can do or what can happen to them, and much less about what is happening in the changes themselves. However, once more, accounts seen as more desirable through the project’s spectacles appeared only slightly more often in the D interviews. In both sets of interviews the pupils elaborated on close to three quarters of the changes they referred to explicitly. As can be expected any special terms used in the accounts of the changes in the A interviews tend to be mainly names of temperatures and of physical states, and less of physical processes, while in the D interviews the equivalent terms used are mainly project terms. The project’s terms that appeared in the pupils explanations of the changes are the terms ‘spread out’ and ‘squash up together’ - a variant of the term ‘bunch together’. While in all ten of these instances the children seemed to hold the correct meaning of the terms, only in two of them did they use them completely appropriately, that is, use them to allude to microscopic changes in the concentration of matter. Microscopic explanations though often encouraged by the teacher in the Year 7 class were not introduced as such in the project’s materials used for that class. We have to interpret, I think, the observed inappropriate use of the project terms as a result of this inaccessibility of ‘micro’ descriptions to the children.

7.2.4 Comparison of pupils’ spontaneous accounts of changes common to first and last interviews

Another way to examine comparatively the two sets of interviews is to look at how the pupils talked about the changes that were common to them (see subsection 5.7.4.4 for details on the process of analysis). These, also indicated in the previous section, were:

- ice forming on a pond
- acid rain eroding a stone statue
- a plant growing
- wood burning
- a hot bath cools down

From the tables in the appendices 7.2 and 7.4 one can see to which other change each of the above changes was linked. So, for example, in the A interviews ‘ice forming on a pond’ was found similar to ‘acid rain eroding a stone statue’ by three groups, to ‘hot lava from a volcano turns solid’ by two, to ‘a hot bath cools down’ and to ‘a car windscreen being shattered’ also by two, and to ‘making soup out of powder soup and water’ by one group. In the D interviews the same change was matched to ‘your body making extra fat’ by all four groups, and to ‘acid rain eroding a stone statue’, ‘a plant growing’, and ‘a hot bath cools down’ by one group. If one looks at the choice of situations presented to the pupils in each set of interviews, one will not fail to notice that in the D interviews all desirable links to and from ‘ice forming on a pond’ were made by one or more of the groups, and that only one match, that with ‘acid rain eroding a stone statue’, made by one group, seems to be less desirable. In the A interviews however three out of the five matches are thought of as less desirable, while none of the groups considered matching ‘ice forming on a pond’ with ‘a plant growing’. Tracing the performance of one particular group across both interviews is not very easy because the composition of the groups did not remain the same (as I explained in subsection 7.2.1). However, I will try to do this for two groups whose composition was minimally changed; that is, they consisted of the same three (out of the participating four) pupils across both sets of interviews. In examining their progress we need to take into consideration that both of these groups of pupils came from the less able half of the class.

7.2.4.1 Finding a match for ‘ice forming on a pond’

We meet the first group linking ‘ice forming on a pond’ to ‘acid rain eroding a stone statue’ in the A interview

“Because they both drop from the sky. Because acid rain drops from the sky and so does the snow and then it forms ice.”

and to ‘your body making extra fat’ in the D interview

“Because that is forming and that is making it - extra fat.”

Although neither of the two explanations can be thought of as very desirable, it is again the case that in the latter explanation the pupils attempted a comparison of the two changes, while in the first one the comparison was restricted to the objects

participating in them. Accounts like the second one can not be seen as very desirable because they seem to treat the changes like events and to pay no attention to the underlying processes that are involved in them.

The comparison of the similarities identified for ‘ice forming on a pond’ by the second group in the two sets of interviews yields the same conclusions. While in the D interview the match identified - ‘your body making extra fat’ - seems more appropriate than the ones identified in the A interview, the explanation that accompanies it falls short of being the one the project would wish for.

7.2.4.2 Finding matches for ‘acid rain eroding a stone statue’ and ‘wood burning’

For the situations ‘acid rain eroding a stone statue’ and ‘wood burning’ not much of a change was observed in the performance of the groups. However, no particular progress was expected for these changes, because both of them concern chemical processes not met by the Year 7 pupils in the classroom.

7.2.4.3 Finding a match for ‘a plant growing’

Contrary to the previous two situations, the situation ‘a plant growing’ had been introduced in the Year 7 classroom using the project’s materials and thus one would expect to see some change in pupils’ reasoning about it. In the A interviews from the choices that are available someone thinking in the project’s way might have matched ‘a plant growing’ to ‘ice forming on a pond’ or to ‘hot lava from a volcano turns solid’, all of them being processes where matter ‘bunches together’. None of the groups chose either of these two matches. In the D interviews, on the other hand, suitable matches would be the ‘ice forming on a pond’ and the ‘your body making extra fat’, both of which were chosen by the pupils, the latter one by all four groups. Exemplifying the above impressions for the two groups previously examined, we see the pupils of the first group linking it to ‘wood burning’ in the A interview and reasoning that

“You can burn the plant as well because it is made out of wood as well.”

and matching it to ‘your body making extra fat’ in the D interview because

“That’s growing and that’s growing. They are both growing.”

Similarly, the pupils of the second group linked ‘a plant growing’ to ‘fruit drying’ in the A interview based on a difference they identified between them:

“That one is drying up and that one is growing. Well, that’s got like food in it and that one hasn’t.”

while in the D interview they matched it to ‘your body making extra fat’ and gave the explanation

“The plant is growing and the man, his thingy - his body’s growing too.”

These two examples do not show anything new. There is a positive shift in the sort of similarities the pupils identified, but nothing more ambitious than that. However, the two groups I am quoting happen to consist of pupils who have considerable difficulties in carefully formulating verbal accounts in English. I believe that this should be taken into consideration when examining the above excerpts. Especially in the quotations that come from the D interviews the pupils seem to do no more than reiterate the terms given in the names of the situations. Let’s compare now these to the following excerpt which appeared in the last interview of a group of more able pupils:

P1: *“When a plant grows the leaves are spreading out and when you get fat, you get fatter when you eat more, and spread out as well.”*

P2: *“When a plant grows it needs loads of food and this body loads of fat, so it can get squashed up together and make it strong and then... And then all the fat swells up inside your belly and it keeps getting bigger and bigger.”*

Here the children attempt to make use of the project’s terms in elaborating their explanations, and although they fail to do it in the most desirable way, they attain richer and more extended explanations.

7.2.4.4 Finding a match for ‘a hot bath cools down’

The first group found the situation ‘a hot bath cools down’ similar to ‘making soup out of powder soup and water’ in the first interview, based on the assumption that a soup is hot, and thus it would also cool down if left for some time. This similarity I called ‘potential’ because it does not arise from the characteristics of the *given* changes, but from the characteristics of *possible* changes imagined as happening to the same objects. The fact that the pupils came up with such a similarity shows once more their difficulty in concentrating on the changes presented to them. Desirable matches for this change would have been ‘ice forming on a pond’ or ‘hot lava from a volcano turns solid’, but none of the two was selected by the pupils. In the last interview the match chosen for ‘a hot bath cools down’ was ‘sweating to stay cool’. The justification given was that in both situations something is cooling down. This match was certainly more appropriate than the previous one, although still not the intended (by design) match, which had been, like before, the situation ‘ice forming on a pond’.

However, the choice of the intended match was not always accompanied by desirable reasoning. The second group of pupils chose ‘ice forming on a pond’ as the match for ‘a hot bath cools down’ in the first interview, but the similarity they identified between the two was merely that they both have water:

“Because that one is hot water - the bath - and that one is cold water.”

In the last interview the same pupils matched the change to the situation ‘sweating to stay cool’ for the same reason as the group mentioned above. The similarity identified this time was clearly more appropriate than in the first interview, since it concerned the process - cooling down - thought to be involved in both situations and not merely the object - water - present in them.

7.2.5 Summary of findings

Summarising the conclusions that came out of the comparative analysis of the first (A) and last (D) interviews, it was found that the pupils could perform the task both with greater ease and more successfully in the last interviews. They could focus better on what was happening in the given changes and possessed a more extended vocabulary to talk about them. In my opinion, these results should be thought of primarily as effects of the teaching intervention, although one cannot ignore the fact that the children’s familiarity with the task was also a factor. More ambitious results showing the pupils reasoning spontaneously about the perceived matter and temperature changes, when identifying similarities between two situations, as a result of the teaching intervention, did not arise, for the reasons explained in the rationale of the analysis.

7.3 ‘Matching’ and ‘comparing’ tasks: Comparison across Year 7 Group 1 interviews

This section contains the analysis of the ‘matching’ (second) and ‘comparing’ (third) tasks across the four interviews for one group of pupils. These tasks were expected to provide information about how well the children managed to use the terms and ideas introduced by the project to account for and compare a variety of familiar and less familiar changes.

The rationale and process of the analysis are explained in section 5.7.5. The findings concerning the Year 7 pupils are presented here under headings which reflect the important ideas introduced by the project to this age group of pupils, and therefore also the prompts (phrases and pictures) used in the relevant pupil interviews.

For reasons of space, I give a detailed report on the findings concerning only one group of pupils (which I will call Group 1). The equivalent analyses for the other two groups (Group 2 and Group 3) can be found in appendices 7.5 and 7.6.

In the conclusions for Year 7 at the end of this chapter (section 7.6), I will draw on the analyses of all three groups.

7.3.1 Concentration change: Matter ‘spreading out’ and ‘bunching together’

7.3.1.1 ‘Spreading out’

The terms ‘spreading out’ and ‘bunching together’ are introduced by the project to describe changes in the concentration of matter. The pupils met these terms in that context for the first time in the topic ‘Water’ in relation to the processes of ‘mixing’ and ‘un-mixing’.

The pupils made little use of the term ‘spreading out’ in the first interview, that is, before any teaching using the project’s materials had occurred. And interestingly they employed it exclusively in macroscopic descriptions. They said that ice spreads out on a pond as it forms and denied that hot lava from a volcano turning solid does because *“it’s just still in one place”*. However, they did not use it in their accounts either of the change ‘a cold drink left out in the sun’ - even though they said that evaporation is taking place -, or of the changes ‘wood burning’, ‘making soup out of powder soup and water’ and ‘acid rain eroding a stone statue’.

Two months later, in the second interview, the pupils used the term more as they had been taught. Four changes were matched by one or more pupils to the abstract picture which represented ‘spreading out’. For two of them, namely ‘cleaning a paint brush in water’ and ‘an explosion’, it was an appropriate match. Moreover, from the two not so appropriate matches only one was retained, being the choice of the three out of the four pupils; the other was discarded promptly by the pupil who suggested it. I call ‘not so appropriate’ the explication of the change ‘your hair growing’ as a spreading out process because it refers to the macroscopic observable event of ‘growing’ as opposed to the invisible physical and chemical processes involved in ‘growing’. ‘Spreading out’ in that case was used together with the word ‘separating’; the use of the term ‘spreading out’ as a synonym of ‘separating’ was something I have also commented on in the analysis of their written assignments in the pupil case studies (see section 6.4). However, it is important to note that the change ‘your hair growing’ was new to them, in the sense that it had not been discussed previously in their lessons. So was also the case for the change ‘an explosion’. For that change,

although ‘spreading out’ is considered an appropriate match, it is clear that the pupils found it difficult to identify what was spreading out and this resulted in unclear macroscopic explanations where fire - treated as a substance - was said to be spreading out. On the other hand when the pupils talked about the change ‘cleaning a paint brush in water’ - similar to changes they had discussed in their lessons on the topic ‘Water’ which had just preceded the interview - their use of the idea ‘spreading out’ appears more elaborated. They did not only specify what is spreading out but also what it is spreading out into (which however was suggested by the name of the situation).

“Paint is spreading out in water.”

In the teaching notes of the project materials it is explicitly stated that pupils should be encouraged to pay attention to both these substances.

In the third (‘comparing’) task, where the pupils were given some pairs of situations and were asked to compare them, the process of ‘spreading out’ was identified inappropriately to be one of the similarities between the changes ‘your hair growing’ and ‘the windows of the car misting up on a very cold day’ and more appropriately between the changes ‘cleaning a paint brush in water’ and ‘an explosion’.

In the third set of interviews, nearly four months later, the abstract picture of ‘spreading out’ was chosen by one or more pupils as a match for every one of the eight situations. The pupils this time seemed a lot more familiar with the term to the point of wanting to apply it to every change without exception. As previously, the least appropriate matches, as for example the matches of ‘warming your hands by the radiator’, of ‘your body staying warm on a cold day’ and of ‘water vapour forms clouds’ to the picture of ‘spreading out’, got in the end rejected even by the pupils who suggested them. Also, as before, the more sophisticated use of the word occurred in relation to the changes they had previously met in their lessons. For example, one of the pupils who paired the change ‘smoke filling the air over a city’ with the abstract picture of ‘spreading out’ also made the point that

“when it gets to the sky there is a lot more room, so it can spread out”.

This remark is clearly influenced by what they had learned about the factors that affect the rate of evaporation (see activity ‘Evaporation - speeding it up and slowing it down’, C8, ‘Air’, 6.2.2.5).

Something else that came across very clearly in this third interview is that the pupils firmly held that evaporation is a spreading out process. They said that evaporation was taking place in the changes ‘a cold drink left out in the sun’, ‘getting salt by evaporating salt solution’ and ‘water vapour forms clouds’ and as a consequence

they matched them to the abstract picture of ‘spreading out’. Once again, the process of evaporation had been extensively elaborated in the project’s activities they had used in their lessons about ‘Air’ and ‘Materials’.

Having said the above, macroscopic accounts of spreading out were not absent from this interview. Indeed, one could say that evaporation is a spreading out process seen both macro- and microscopically, so the fact that the pupils identified it as such does not mean that they referred to what is happening to the particles of the evaporating substance. In relation to the changes ‘melting wax’ and ‘wood burning’ ‘spreading out’ was used to mean ‘going in all different directions’. For ‘wood burning’ - a chemical change not taught to them - there was the additional problem of specifying the substance that was spreading out.

The fourth interview, after almost one and a half months of teaching, presents more or less the same characteristics as the third. The idea of ‘spreading out’ was applied to every one of the eight situations. This time all the inappropriate matches were rejected, and interestingly the rejection in one case - about ‘your body making extra fat’ – was justified on the grounds that it treated the change as an event and ignored the processes involved. As with evaporation in the third interview, it is in the pupils’ discussion of ‘growing’ that one can see how the ideas of the project have been internalised. Only one out of the four pupils seemed to suggest that in the changes ‘a plant growing’ and ‘your body making extra fat’ something was spreading out; his suggestion was discarded without discussion in the first case, while in the second it was given a brisk dismissal.

What I found very important and unexpected was that in this interview, contrary to the previous one, the pupils’ use of spreading out in the account of ‘wood burning’ was very satisfactory. In justifying his choice one pupil said:

“...the wood turns into ash and like all the little particles in it spread out.”

The change in the nature of the wood was perceived here as being one of spreading out. Moreover, the pupil explicitly attempted a microscopic description of the change. ‘Wood burning’ was one of the changes not discussed in the Year 7 materials, so I am inclined to attribute the above advanced account to the familiarisation the pupils had with the idea and use of ‘spreading out’.

Consistently with the above reasoning, in the ‘comparing’ task of this interview ‘wood burning’ was found first similar to ‘sweating to stay cool’ and second to ‘running and using up food’; in all three of them something was seen as spreading out. More importantly however, faithful to a microscopic interpretation of ‘spreading out’, such as the above, the children, when asked by the interviewer, categorically

denied that the phrase ‘something spreads out’ might be true for the change ‘ice forming on a pond’:

“Nothing is spreading out there - it’s going hard.”

7.3.1.2 ‘Bunching together’

The idea of ‘bunching together’ was somehow less prompted and used compared with that of ‘spreading out’ both by the teacher in the lessons and by the pupils in the interviews.

Contrary, to the case of ‘spreading out’, right from the first interview the pupils were able to identify the change of state taking place in freezing as a ‘bunching together’ process. Having said this, the change ‘the windows of the car misting up on a very cold day’ in the second interview was identified as a ‘bunching together’ change only by one pupil, who eventually changed his mind in favour of the description ‘appearing from nothing’, because he said that he had mistaken mist to be frost. It is not clear what he meant.

For the ‘unmixing’ changes appearing two months later in the second interview the pupils did not always choose the abstract picture for ‘bunching together’. However, for the change ‘crystals forming in copper sulphate solution as it cools’ which they had studied theoretically and experimentally in the classroom they did, and talked about the copper sulphate solution bunching together to make crystals. They preferred to match ‘purifying water’, however to the ‘unmixing’ abstract picture.

Interestingly, ‘cooling down’ was also seen as a ‘bunching together’ process; the heat treated as a substance-like quantity was said to be ‘bunching together’ when an electric iron cools down after being switched off. This match was eventually discarded in favour of the match to the abstract picture of ‘disappearing’.

Whether ‘bunching together’ was understood as happening microscopically or not, it is difficult to say. While the ‘freezing’ changes of state were most of the time identified correctly as ‘bunching together’ processes, in the third interview - i.e. close to six months after the start of the intervention - we see the children matching the change ‘melting wax’ to the abstract picture of ‘bunching together’ because *“it is getting like smaller”* or because *“it won’t stay the same height, will it?”*; both justifications derive from macro observations.

What is clearly different in the fourth interview is that the changes of ‘growing’ such as ‘a plant growing’ and ‘your body making extra fat’, which in the previous interviews were described mainly as ‘spreading out’ events, this time were talked about as ‘bunching together’ processes. However, it is also clear that the pupils had

difficulties in specifying the subject of ‘bunching together’ in these changes. For ‘a plant growing’ for example a pupil referred to *“all the goodness”* ‘bunching together’, another disagreed and suggested instead that it is *“food”* that is ‘bunching together; and a third one called it *“the thing from its roots”*. As for the change ‘your body making extra fat’ the term ‘bunching together’ was used as a transitive verb, that is ‘bunching together’ was seen as an action of the body on the food.

7.3.2 Physical change: Matter ‘mixing’ and ‘un-mixing’

The ideas of ‘mixing’ and ‘un-mixing’ were explored in the topic ‘Water’ and relevant abstract pictures appeared in the second interview. Their use in relation to the studied changes is very satisfactory. As one could have expected, the more the pupils knew about the situations, the more elaborate their explanations were. For the change ‘purifying water’ for example, the process of ‘un-mixing’ was explained as follows:

“If there is salt in there, or something like - the solution - and then you put it through a filter and then you got two separate.”

This explanation is at a general level because it does not specify the products of ‘un-mixing’; however, it suggests a concrete mechanism for achieving the change.

However, ‘mixing’ and ‘un-mixing’ were also used less appropriately. The ‘mixing’ picture was chosen as a match for the changes ‘your hair growing’, ‘warming your hands by the fire’ and ‘an explosion’. It was eventually kept as a match only for the change ‘warming your hands by the fire’.

For ‘your hair growing’ it was clear that the children attempted to use the word to describe the chemical changes they thought as taking place:

“All the liquids in your hair are mixing to make your hair grow longer.”

The same was with the change ‘an explosion’. Only this time they also tried to name the mixing components; their lack of knowledge about the participants and processes involved in the change accounts for the fact that they came up with names of objects (e.g. engine, or car) as opposed to substances as the mixing parts of the change.

What I found worrying, however, was the use of ‘mixing’ to describe what is happening when one warms one’s hands near the fire. In this description ‘heat’ and ‘the hands’ were treated as material substances that can be mixed to produce ‘warm hands’.

7.3.3 Chemical change:

‘A substance changes’ - ‘It makes a new substance’

As already mentioned, the Year 7 pupils were not taught about chemical changes. However, they examined briefly the difference between a change of a substance and a change of an object. Bearing this in mind, it is interesting to examine what they considered as a change of substance.

In the first interview they chose the expression ‘a substance changes’ as true for all the situations presented to them, even for the situation ‘a hot bath cools down’ in which the only identified change was that of the temperature of the system. In other words, they seemed to employ it to mean ‘something changes’ not paying any attention to whether this ‘something’ is a substance. With the phrase ‘it makes a new substance’, they were more cautious. They picked it as appropriate for all the situations in which they identified a material change, irrespectively of whether this was a physical or a chemical change. Most of the times the identification of this change was in concrete terms at the level of the object. For example the phrase ‘it makes a new substance’ was proposed as true for the situations ‘ice forming on a pond and ‘hot lava from a volcano turns solid’

“Because the water in the pond becomes ice and lava from the volcano becomes solid.”

Similarly, ‘a plant growing’ makes a new substance *“from a seed to a plant”*. In other words the pupils seemed to look for whether, as a result of the change, there was a new ‘object’ made, that is, a macroscopic entity that did not exist as such at the start of the change; the process of the change itself was ignored. A further example that illustrates this point is that in the case of the situation ‘acid rain eroding a stone statue’ the pupils on the one hand reasoned that ‘a substance changes’, but on the other denied that a new substance is made - the statue was seen as in some way disappearing as a result of the change:

“This is going to vanish - it changes from something to nothing”.

In the third interview, almost six months later, where the pupils were asked to say whether they thought the phrase ‘it makes a new substance’ describes appropriately a selection of six changes, the use of the phrase appeared slightly more refined. Evaporation and condensation were as before treated as processes which result in the making of a new substance, but this time with some voiced objections. The process of melting, on the other hand, presented no such difficulties; for the change ‘melting wax’ the pupils easily agreed that

“It is going to stay the same. Except it [the wax] is going to be melted.”

Interestingly, after a month and a half, in the final interview the pupils seemed considerably more reluctant to identify the making of a new substance in a set of six situations, four of which involved chemical changes. So, no new substance was seen as being made in ‘a plant growing’, ‘your body making extra fat’ and ‘running and using up food’. The argument for all three seemed to be that nothing ‘new’ was made, that is, nothing that did not exist before.

“Fat isn’t a new substance, it’s always in our body.”

was the explanation given by the lesser able pupil of the group, and was not challenged despite the fact that another pupil had previously expressed a different opinion. I find this reasoning to be essentially the same as the reasoning observed in the first interview. I tentatively however also note that some kind of shift happened in the way the children reasoned about the physical changes. About the freezing of water in the situation ‘ice forming on a pond’, after some reflection instigated by the interviewer and contrary to what they had reasoned in interview A, the pupils concluded that it does not result in a new substance.

“It’s water, but it’s hard - that’s all. So it doesn’t really make a new substance.”

They also thought the same for the situation ‘sweating to stay cool’.

7.3.4 Maintaining a concentration difference

7.3.4.1 ‘Substances stay the same’ - ‘No change’

The phrase ‘substances stay the same’ was used only in the first interview and the pupils made no use of it. The equivalent abstract picture in the subsequent three interviews was called ‘no change’. This was not chosen as a match for any of the eight situations in the second interview, even though it would have been an appropriate match for the situation ‘warming your hands by the radiator’ - matched instead to the abstract picture of ‘mixing’ - and for the situation ‘an electric iron cools down after being switched off’ - matched to ‘disappearing’.

In the third interview the pupils correctly identified the situations which did not involve a change in matter. However, from the explanations that the children gave it seems that what they considered in deciding was whether there was any apparent macroscopic change in the participant(s) of the change, and not whether there was any change in its internal structure. As for the fourth interview, the situation that was intended by the design of the interview to be matched to ‘no change’ - ‘a hot bath cools down’ - was thought of by the children as involving the process of evaporation

(which is not wrong, though not intended) and was thus matched to the picture of ‘spreading out’.

7.3.4.2 ‘Keeping a balance’

The abstract picture of ‘keeping a balance’ which aimed at prompting the pupils’ ideas about structures which remain unchanged through the flow of matter in and out of them was used only in the last interview. The evidence is insufficient to permit any ambitious interpretation. It was discussed only in relation to the situations ‘running and using up food’ and ‘ice forming on a pond’ and was suggested by only one pupil each time. In both cases, there was a strong objection from at least one of the other three pupils. In the first case, its use implied some kind of flow of matter - a person uses up food but also replaces it by eating more - and was rejected on the basis that it was not strictly relevant to the situation. In the second case however, it was used to express the absence of change in the amount of matter perceived statically. This interpretation was briskly discarded by the rest of the pupils.

7.3.5 Temperature change

The expressions ‘something gets colder or less hot’, ‘something gets warmer’ and ‘temperature evens out’ were used in the first interview, whereas the abstract pictures called ‘difference in temperature disappears’ and ‘difference in temperature appears’ were used in the third interview; the second and fourth interview did not include (by design) either phrasal prompts or abstract pictures of temperature changes.

7.3.5.1 Phrases: ‘Something gets colder or less hot’ - ‘Something gets warmer’ - ‘Temperature evens out’

In the first interview the pupils eagerly applied one or both the phrases ‘something gets colder or less hot’ and ‘something gets warmer’ in their description of all given situations. They felt so confident with the ideas behind them that they ended up forcing their use in inappropriate matches. Moreover, the wording of the two expressions seemed to encourage the pupils to pay attention only to the temperature change of the system and to ignore the role the temperature difference between the system and its surroundings played in this change. This was the case more when the pupils talked of a cooling down process. In other words I got the impression that the surroundings and/or its temperature was considered more important when the temperature change identified was one of warming. Consistently also with the wording of the phrases, the temperature change of the system was mostly identified in relative terms.

The expression ‘temperature evens out’ presented even greater problems than the other two, as its meaning did not seem so transparent to the pupils. As a consequence it was only used for three situations - appropriately only for two - while it could have been matched to a further three. The temperature of the surroundings was as before ignored, whereas the temperature of the system in two of the situations was seen as changing - in each case ending up as ‘warm’ (in the sense of neither hot nor cold) - and in the third one (‘a plant growing’) as evenly spread.

7.3.5.2 Picture: ‘Difference in temperature disappears’

The identification of temperature changes and the explanations that followed were significantly more elaborate and sophisticated in the third interview, after almost six months of teaching. I will examine the use of each of the abstract pictures separately. The abstract picture ‘a difference in temperature disappears’ was chosen as a match for six out of the eight situations presented in the interview; in all cases it was an appropriate choice. What is more important though is that, contrary to what was observed in the first interview, in all the justifications the pupils gave for the matches they made, the temperature of the surroundings at the start of the change was identified as well as the temperature of the system; sometimes the temperature of the system was even identified relatively to that of the surroundings. The consideration of both temperatures in thinking about thermal changes is important because it can lead to or imply the identification of a temperature difference. In all situations matched to this picture the temperature of the system was thought of as changing. The temperature the system would end up as being was not always specified, though more than few times it was acknowledged that it would end up the same as that of the surroundings. Interestingly, in the cases where the temperature of the system was said to be changing only with reference to itself, the surroundings and/or its temperature was seen as causally related to this change. For the change ‘warming your hands by the radiator’ for example it was said that:

“The hands begin to get warmer by the radiator because of the heat.”

The temperature difference between the system and its surroundings was never explicitly identified as the cause of the temperature change.

7.3.5.3 Picture: ‘Difference in temperature appears’

The idea behind the abstract picture ‘a difference in temperature appears’ was not used with the same facility. It was applied to five out of the eight situations by one or more pupils, but it was finally kept as a match to only one of them. The pupils seemed to find difficulties in identifying correctly the system and the surroundings. In the situation ‘a cold drink left out in the sun’ for example the drink was seen by

one pupil as becoming warmer than the glass it is found in. Likewise in the situation ‘getting salt by evaporating salt solution’ the salt was said to become colder than the water. Neither of the two explanations withstood the criticism of the other pupils, but nevertheless betray some sort of uneasiness with the use of this abstract picture. Another source of confusion seemed to be the definition of the ‘Before’ and ‘After’ instances for the changes ‘melting wax’ and ‘getting salt by evaporating salt solution’. This is clear in the following quotation about ‘melting wax’:

“Because this is burning - so it’s hot and the wax is cold and after it is burnt it gets colder.”

It is true that the understanding and correct application of the idea behind the abstract picture ‘a difference in temperature appears’ was cognitively non-trivial. It required that the pupils considered many variables at the same time. They had to consider the temperatures of the system and its surroundings and examine whether these are the same; then they had to think of them changing both in relation to what they used to be and in relation to each other, so that the system and its surroundings end up at different temperatures. Furthermore the picture was not to be read as showing that necessarily both temperatures have to change. The following quotation shows how easily a misunderstanding can occur if one of these requirements is ignored. In the situation ‘a cold drink left out in the sun’ a difference in temperature was said to appear:

“This one is cold - the drink is cold - so when it evaporates it gets hotter, and this is the air outside and then it goes down. The cold drink makes the air surrounding colder.”

In the above quotation the requirement that the system and its surroundings should start from having the same temperatures in the ‘Before’ instance was ignored, and as a result the match was inappropriate.

7.3.6 Maintaining a temperature difference

The expression ‘temperature stays the same’ was used in the tasks of the first interview, whereas the abstract pictures showing a ‘difference in temperature is maintained’ and ‘no change’ in temperature appeared in the third interview.

7.3.6.1 ‘Temperature stays the same’ - ‘No change’

In the first interview the pupils did not choose the expression ‘temperature stays the same’ for any of the situations presented to them. It could have been applied to the changes ‘a plant growing’, ‘making soup out of powder soup and water’ and ‘acid rain eroding a stone statue’.

Nearly six months through the intervention, in the third interview the abstract picture ‘no change’, which shows the system and its surroundings being at a constant temperature before and after the change and at the same temperature as each other, was chosen only once appropriately in relation to the situation ‘smoke filling the air over a city’; a choice that was not defended and was later discarded in favour of another match. For two other situations the idea of ‘no change’ was used inappropriately; the pupils seemed merely to identify an absence of change in the temperature of the system without paying attention to the temperature of the surroundings or its relation to the temperature of the system. This could be explained by saying that the pupils failed to correctly interpret the abstract picture, but rather responded to its linguistic prompt of ‘no change’.

7.3.6.2 ‘Difference in temperature is maintained’

Contrary to what was noted above, in using the abstract picture ‘difference in temperature is maintained’, the pupils in all cases identified a temperature difference. This was not, however, always between the system and its surroundings; in ‘getting salt by evaporating salt solution’ a temperature difference was said to exist between the salt and the water both while the solution is being heated and after the water has evaporated. This suggestion was emphatically rejected by the other pupils and the situation was thought to be more appropriately matched to the picture ‘difference in temperature appears’. Having said that the pupils attempted to identify a temperature difference, they however did not always trace its constancy before and after the change as the abstract picture suggests and this is exemplified in the example I just gave about the situation ‘getting salt by evaporating salt solution’. In other words, whereas two elements were thought to be at a different temperature to each other before and after the change, they were not said to maintain this temperature difference during the change. This observation is similar in essence to the one made above about the ‘no change’ abstract picture; it seems that the pupils found it difficult to reason concurrently about the temperature relationship of two elements to each other and its change with time.

7.3.7 Spontaneous and non-spontaneous change

7.3.7.1 ‘It happens by itself’ - ‘Someone makes it happen’

The idea behind the expressions ‘it happens by itself’ and ‘someone makes it happen’ is the spontaneity of a change. These expressions are the ones the project’s authors were considering using to describe spontaneous and non-spontaneous changes at the time I conducted the first set of interviews with pupils. However, the pupils’ use of these expressions in those interviews pointed to one possible pitfall of

the expression ‘someone makes it happen’; it seemed to lead the pupils to look for the likely presence of a human agent in a change, which was something neither intended nor desired by the project. As a result, in the final version of the project’s activities, as well as in the version used for the intervention in Years 7 and 8, the authors changed these phrases to ‘it just happens’ and ‘it does not just happen’, which they hoped would avoid this pitfall. However, a decision was taken to keep the original expressions as prompts in the interviews so that it could be possible to compare pupils’ relevant performance across all four interviews. Having said this, the expression ‘someone makes it happen’ was used only once more as a prompt, in the second set of interviews, whereas the expression ‘it happens by itself’, which is not very dissimilar to the project’s equivalent expression ‘it just happens’, appeared in all three (four in total) remaining interviews.

In the first interview the phrase ‘it happens by itself’ was interpreted by most of the pupils of Group 1 to mean the absence of an agent in a change, and more particularly sometimes to mean the absence of human action. So, it was easily used in the description of physical changes - mainly changes of state - especially if the cause of the change was not obvious to the pupils. It was thus easily chosen to characterise the situations ‘ice forming on a pond’ and ‘hot lava from a volcano turns solid’, whereas its choice for the situation ‘a cold drink left out in the sun’ was met with scepticism:

P1: *“But the sun might make it do it.”*

P2: *“Yes, the sun. Something is doing it.”*

The phrase ‘someone makes it happen’, as said before, seemed to prompt the children to attribute the change directly or indirectly to a human action. This further resulted in that some of the changes were talked about as events performed or launched by a human agent. In the situation ‘a plant growing’ for example, *“someone has to plant the seed”* and in the situation ‘acid rain eroding a stone statue’ human activity was deemed responsible for the existence of acid rain.

The same characteristics were also present in the use of these two phrases in the second interview, two months later. In the third interview, six months after the start of the intervention, the interpretation given to the expression ‘it happens by itself’ seemed slightly more sophisticated. It seemed to acquire the additional meaning of something that is happening ‘naturally’. For ‘a cold drink left out in the sun’ for example, it was agreed after considerable discussion that:

“Apart from people putting drink in the glass and the straw, everything else happens naturally.”

This seems very acceptable, but (as the project found when using the expression ‘it happens naturally’) it can be and is understood differently from ‘it happens by itself’. For example, the same interpretation was also present in the justifications given for the pertinence of the expression regarding the changes ‘water vapour forms clouds’ and ‘your body staying warm on a cold day’.

It is also worth noting that in neither the second nor the third interview did the pupils seem to relate the decision of whether a change happens by itself with what was thought of as happening to the particles and temperature of the system. This point is quite important because the project’s materials for Year 7 explicitly encouraged the pupils to think of ‘spreading out’ as a process which ‘just happens by itself’.

7.3.7.2 *‘It is easy to reverse the change’*

Something similar to what was observed in the use of the phrases ‘it happens by itself’ and ‘someone makes it happen’ seems to have occurred in the use of and the meaning attributed to the phrase ‘it is easy to reverse the change’ in the course of the four interviews. That is, they were expanded to incorporate more desirable interpretations. This expansion however was rather observed in how the pupils defined the ‘reverse change’ for each situation, than in whether they saw it as being easy to happen.

Once more the physical changes seemed to present fewer problems to the pupils right from the first interview; for both the situations ‘ice forming on a pond’ and ‘hot lava from a volcano turns solid’ the reverse changes were specified to be the ones that would result with the original components expressed in concrete terms: making ice into water and returning a rock back into lava respectively. In the first case the process necessary to reverse the change was also identified: “*warm it up - melt it*”. For the chemical changes however, to ‘reverse a change’ seemed to mean to stop an event or rather not to let it happen in the first place, both of which imply the existence at some point of human agency. Accordingly, the easiness of the reverse change was discussed in the context of what is humanly possible and easy. This way of reasoning was very much present in both the first and last interview. The reversal of ‘wood burning’ in both interviews for example consisted of pouring some water over it. However, in the last interview a different opinion was voiced:

“No. Wait listen. If the wood is already burning you can’t make it back in.... I mean, if the wood’s turning to ash you can’t make it back into wood, can you?”

While I feel cautious about giving this voice* too much significance, I welcome the fact that the same pupil followed the above line of reasoning in relation to two other situations as well. For the situations ‘running and using up food’ and ‘sweating to stay cool’ he said respectively:

“You can’t make the person run back and then can’t make the food come out of him again.”

and

“You can’t get the sweat back into a person’s body.”

It is clear that in all three cases the reverse change was defined strictly as the one that not only results in producing the same initial instance by retaining the identity of the participants, but also follows the reverse path in doing so.

7.3.8 Summary of findings

What one notices in the above accounts is that overall the pupils showed progress in their use of the ideas suggested by the project to describe what is happening in different changes. The progress was sometimes small and difficult to detect, and sometimes was exemplified in the performance of one pupil, but it was clear that there was no regression.

These and other traces of progress (or their absence) were looked for in the interviews of another two groups of pupils. The analyses of these interviews can be seen in the Appendix (appendices 7.5 and 7.6).

Finally, the analyses of all three groups are brought together in the discussion of the conclusions concerning the use of the project’s approach and materials with the Year 7 pupils (section 7.6).

7.4 Situations common to more than one interview: Comparison of explanations

This section summarises the results of the analysis done of the accounts that the pupils gave aided by the use of abstract pictures and phrases (i.e. as part of the interview tasks ‘matching’ and ‘comparing’), for the situations which were common to more than one interview.

* A helpful reminder that members of a group are also individuals and that perceived group trends are influenced by individual performances.

These situations were:

- a hot bath cools down
- ice forming on a pond
- acid rain eroding a stone statue
- a plant growing
- a cold drink left out in the sun
- warming your hands by the fire/radiator
- wood burning

For each of these situations I identified the interviews in which it was discussed and the common prompts (abstract pictures or phrases) which were used for its discussion. I then compared how the pupils applied the ideas represented by these common prompts to the given change in the respective interviews (see section 5.7.6).

As before, this comparison was done for three groups of pupils. These analyses can be found in appendices 7.7, 7.8 and 7.9.

The results of these analyses were consistent with the findings already reported in previous sections: overall, there was some progress in the accounts the pupils gave for the above changes by the end of the intervention, but in some cases this progress was subtle. The only change for which almost no progress was found was ‘acid rain eroding a stone statue’. However, not much progress was expected for this change anyway, since it deals with a chemical process not addressed by the teaching materials used with the Year 7 pupils.

On the whole, the observed progress was more subtle in the pupils’ accounts of concentration changes; the macroscopic descriptions of them were still very much present even in the last interview. For example, whereas all three groups agreed that ‘ice forming on a pond’ is a ‘bunching together’ change, a significant number of pupils amongst them also argued that it is a ‘spreading out’ one, because ice is spreading out over the lake. Another good example is the situation ‘a plant growing’. Most of the pupils in the last interview remembered from their lessons that it is a ‘bunching together’ change. However, none was certain about *what* exactly is bunching together. Moreover, there were also those pupils who insisted that a plant is ‘spreading out’ as it grows.

The pupils’ progress concerning the ideas of spontaneity and reversibility was also subtle. By the end of the intervention, the pupils seemed still to hold quite strongly the notion that some kind of agency (often human) is driving most of the changes.

Having said this, in the last interview, all three groups succeeded in seeing ‘wood burning’ as a spontaneous and not easily reversible change.

Finally, the progress observed in the pupils’ accounts of thermal changes was remarkable. With the aid of the abstract pictures the pupils rarely failed to identify the relevant temperature differences and their disappearance.

7.5 ‘Grouping’ task: Comparison of all Year 7 last (D) and Year 8 first (A) interviews

This section evaluates the effects of the novel teaching approach on the pupils’ ability to abstract similarities between different changes. It does this by comparing this ability in two groups of pupils: the Year 7 pupils who had been taught using the materials; and a group of pupils of approximately the same age who had not used the project’s materials. The data used for this purpose are the transcripts for the ‘grouping’ task of the Year 7 pupils’ last (D) set of interviews and of the Year 8 pupils’ first (A) set of interviews. The analysis involved looking at the justifications each Year’s pupils gave for linking two situations, and identifying the features of the changes they paid attention to when reasoning about particular changes (see section 5.7.7).

7.5.1 Pupils identifying similarities

7.5.1.1 *Kinds of groupings*

The first thing I compared was the relative frequency of the groupings the pupils had made, using the categories discussed in subsection 5.7.4.2 (see Table 7.3).

INTERVIEWS ‘GROUPING’ TASK	‘Similarities’ ‘Opposites’	Script	Arbitrary	No reason Unclear
Y7 D Interviews (<i>n</i> = 31)	85%	3%	6%	6%
Y8 A Interviews (<i>n</i> = 33)	75%	0%	15%	10%

Table 7.3 *Kinds of groupings suggested in the Y7 D and Y8 A interviews*

The pupils who had been exposed to the approach made ‘similarities’ or ‘opposites’ matches at the increased frequency of 85% compared to 75% for the ones who had not. These latter seemed not to be as able to focus on the given changes and as a result they either were unable to give justifications for their matches, or drifted to other imagined associated changes hence their increased number of ‘arbitrary’ matches.

7.5.1.2 ‘Similarities’ and ‘opposites’

Comparing further the sort of similarities and differences the pupils identified between two situations (see process of analysis in subsection 5.7.4.2) I found that in the Year 8 interviews 22% of the similarities and differences identified, concerned what were perceived as the participants in the changes and their properties rather than the changes themselves; these were only 4% in the Year 7 interviews (Table 7.4).

INTERVIEWS ‘GROUPING’ TASK	‘SIMILARITIES’ AND ‘OPPOSITES’		‘SIMILARITIES’ AND ‘OPPOSITES’	
	Between Objects and Properties	Between Changes	Actual	Potential
Y7 D Interviews (n=26)	4%	96%	93%	7%
Y8 A Interviews (n=54)	22%	78%	66%	34%

Table 7.4 Kinds of ‘similarities’ and ‘opposites’ in the Y7 D and Y8 A interviews

What this suggests is that the pupils of the project were more adept in considering what was happening in the changes and drawing similarities based on what they thought this was. Moreover, what they thought was happening in the given changes corresponded 93% of the times to what was ‘actually’ suggested by the name of the situation rather than to what could ‘potentially’ happen (Table 7.4). The ‘actual’ similarities were only 66% in the Year 8 interviews. Similar trends were also recorded in the corresponding Year 7 analysis (see subsection 7.2.2.2).

However, considering all the similarities identified, the percentage which referred to a physical or chemical change, that is the more desirable similarities, was bigger - 56% compared to 42% - for the pupils who had not been exposed to the project’s approach. The fact that a similar result seemed also to arise in the equivalent Year 7 and 8 analyses (see subsections 7.2.2.2 and 9.2.2.2) (only at a much lesser extent), suggested to me to look for whether this result could have been an artefact of the kind of situations presented to the pupils in each of the first and last interviews. Although a conscious effort was made so that each set of situations presented to the pupils in each interview would cover a variety of physical and chemical changes, the percentage of the ‘easier’ physical changes - considered as such because they either were very familiar to the children, e.g. ‘a cold drink left out in the sun’, or because they suggested the relevant physical process in their name, e.g. ‘scent or after-shave evaporating from the skin’ - seemed to be bigger in the first set of interviews. On the

other hand, this bias could be seen as being partially countered by the fact that some of the situations the pupils met at the last interview had been previously explicitly discussed in their classroom.

In accordance with the previous results I also found that in the Year 8 interviews compared with the Year 7 the pupils focused much more on the objects present in the situations and on what they were and what could happen to them, than on what was actually happening during the change. However, once more, accounts seen as more desirable from the project's point of view appeared more in the Year 8 interviews. As expected, only the inducted pupils made use of project terms to describe the changes, that is, only they attempted to identify changes in concentration of matter - spreading out or bunching together. The Year 8 pupils preferred to make use of names of processes or of names of temperatures and physical states to describe the changes.

7.5.2 Comparison of pupils' spontaneous accounts of changes common to Year 7 last and Year 8 first interviews

As before the two sets of interviews were compared by looking at how the pupils talked about the changes that were common to them and for which there was the expectation that a shift might have occurred. These were:

- ice forming on a pond
- a plant growing
- a hot bath cools down

From the tables in the appendices 7.3-7.4 and 9.1-9.2 one can see to which other change each of the above changes was linked. The situation 'ice forming on a pond', for example, was matched to 'your body making extra fat' by all four groups, and to 'acid rain eroding a stone statue', 'a plant growing', and 'a hot bath cools down' by one group in the Year 7 interviews. In the Year 8 interviews, the same change was matched to 'a hot bath cools down' by three groups, and to 'acid rain eroding a stone statue' and 'hot lava from a volcano turns solid' by one group. All matches with the exception of the one with 'acid rain eroding a stone statue' seem to be desirable in both interviews, but one cannot overlook the fact that the pupils of the project chose to focus on the change in the concentration of matter and thus all decided to match it to the change 'your body making extra fat' than to the much more obvious temperature change of 'a hot bath cools down' which was the favourite match of the Year 8 pupils.

In the Year 7 interviews ‘a plant growing’ was matched only appropriately - to ‘your body making extra fat’ by all four groups and to ‘ice forming on a pond’ by one - whereas in the Year 8 interviews it was not matched to any of the changes in which matter ‘bunches together’, but rather to ‘wood burning’ by two groups, and to ‘fruit drying in the sun’ and ‘digesting food’ by one group.

Finally there was no difference in the kind of matches the pupils made with the situation ‘a hot bath cools down’. The identification of a temperature change did not present any difficulties to the pupils and this agrees with other results that have been presented in this thesis.

7.5.3 Summary of results

What was established by the comparative analysis of the Year 7 last and Year 8 first interviews was that the pupils who were exposed to the project’s approach managed to focus on what was happening in the given changes with greater ease and attempted to draw similarities based on this. They also seemed to be considerably more keen to identify concentration changes, which they described using project terms. However, their identification of similarities was worse overall, since they were based on treating the changes as ‘events’, rather than on acknowledging the processes involved in the changes.

As explained in the rationale, the importance of this analysis is that it provided us with an indication as to whether the new approach is a valid one even when it is not used in ideal circumstances, that is consistently and continuously over the period of some years. The above interpretation of the data suggests that this indication is on the whole positive. The pupils who were taught using the project’s materials were overall not worse off compared with their peers who were not.

7.6 Conclusions concerning the use of the project’s approach and curriculum materials with Year 7 pupils (R.Q. A2.3)

Drawing on all the previous pieces of analysis concerning the use of the project’s materials with the Year 7 pupils, in this section I will discuss whether the pupils showed any progress with respect to the particular objectives the project had set for them (see research question A2.3 in section 5.5).

7.6.1 Differences in concentration of matter

- **Did the pupils pay attention to differences in concentration and identify matter ‘spreading out’ and ‘bunching together’, ‘mixing’ and ‘unmixing’?**

One of the objectives of the project’s teaching materials for Year 7 was that the pupils started paying attention to differences in concentration and identifying matter ‘spreading out’ and ‘bunching together’, mixing and ‘unmixing’. Undoubtedly, the pupils showed progress with the use of these ideas; during the course of the intervention they used them increasingly more consistently and more desirably in their explanations of change. Having said this, it is also true that the pupils often used the ideas inappropriately in macroscopic descriptions of changes. For example, they often identified the process of ‘spreading out’ when objects were seen as ‘separating’, independently of whether the particles involved ended up more or less concentrated. This tendency for pupils to give macroscopic accounts could be explained in more than one way. The terms ‘spreading out’ and ‘bunching together’, assigned by the project to describe concentration changes, clearly carry everyday macroscopic connotations and thus might have encouraged such descriptions. The project’s materials used for Year 7 did not address the teaching of the particle nature of matter and thus did not *explicitly* relate the use of these terms with changes in the concentration of particles. Finally, though the teacher (Anna) encouraged pupils to talk about what is happening to the particles in the changes, in her own accounts she seemed to move between the macro and micro realm without much care.

More sophisticated uses of these ideas occurred in relation to changes which the pupils had previously discussed in their lessons and/or to changes of which the macroscopic behaviour alludes to the microscopic one, e.g. evaporation changes. Overall, the majority of pupils managed to identify matter spreading out in situations as diverse as ‘cleaning a paint brush in water’, ‘smoke filling the air over a city’, ‘sweating to stay cool’ and ‘running and using up food’. Similarly a few pupils reasoned that matter is bunching together in a variety of situations, such as ‘crystals forming in copper sulphate solution as it cools’, ‘purifying water’, ‘your body making extra fat’ and ‘a plant growing’.

Overall, the idea of ‘bunching together’ was less well used compared with that of ‘spreading out’ both by the teacher and in the materials (including the interview tasks). The teacher did not feel very comfortable with it and the Year 7 project’s materials put the emphasis more on spontaneous processes and in this case on concentration differences which disappear by ‘spreading out’. This could have been the reason why the pupils on the whole seemed to find it harder to identify the

‘bunching together’ processes. This could be noticed particularly in the interview tasks. The pupils seemed to favour accounting for the given situations in ‘spreading out’ terms, and thus attempted to identify ‘spreading out’ processes in them sometimes at the cost of misconstruing the meaning of the situations. For example, given the situation ‘water vapour forms clouds’ most pupils talked about the evaporation and spreading out of water to form water vapour rather than about the relevant condensation and bunching together of water vapour into water to form clouds. There was a major change in pupils’ use of ‘bunching together’ in the last interview. They used it more frequently as they attempted to apply it in descriptions of biological changes, and particularly of ‘growing’. This use provoked some interesting and desirable discussions amongst pupils, though some of the explanations given rather suggested that they were applying the idea in a macroscopic sense and were not thinking about what might be happening to particles.

Finally, there is very little evidence that the pupils associated the processes of ‘mixing’ and ‘unmixing’ with those of ‘spreading out’ and ‘bunching together’. Anna herself found it difficult to combine these ideas. The exception was the case of gases; the idea that gases mix and spread out was promoted repeatedly by Anna and was adopted easily by the pupils.

7.6.2 Temperature differences

- **Did the pupils pay attention to existing differences in temperature and identify their disappearance?**

Another of the objectives the project’s teaching materials had for Year 7 was that the pupils started paying attention to existing temperature differences, and identified that such differences tend to disappear. The project also hoped that at the end of the intervention the pupils might have gained some appreciation of the fact that changes of state are driven by temperature differences.

There is no doubt in my mind that the first two objectives were fulfilled. Even before any teaching using the project’s materials took place the pupils could easily identify a temperature change. Their accounts of it however centred on the temperature of the system before and after the change. The surroundings and/or its temperature were hardly acknowledged. Even when they were acknowledged by the pupils, often in warming up changes, they were portrayed as the causal agents of the temperature change, a perception not desirable from the project’s point of view. For example, in the situation ‘a cold drink left out in the sun’ most of the pupils at the start of the intervention said that the sun (or the hot sun) is heating up the drink.

Nevertheless, it was not only that the pupils at the start did not seem to pay attention to the existing temperature differences between the system and its surroundings, they furthermore did not seem to appreciate that these differences tend to disappear, that is that the two temperatures tend to equalise as a result of the temperature changes observed.

With the aid of the abstract pictures and the project's activities the pupils' accounts of thermal situations changed significantly. They now paid attention to the temperature differences (or their absence) between the system and its surroundings, which they indicated either by acknowledging both their temperatures in absolute terms, i.e. 'cold', 'hot', or by stating the temperature of one in relative terms to the other, i.e. 'colder', 'hotter'. Furthermore, many pupils now identified explicitly and consistently the disappearance of these differences, usually by asserting that system and surroundings would end up at the same temperature.

Therefore, the pupils' progress with respect to identifying temperature differences and their disappearance was noticeable and much more straightforward to ascertain than the pupils' progress with other ideas of the project. Strangely, the attention paid to these ideas during the lesson was not conducive to such a progress; two out of the project's three activities on temperature changes were done in the absence of the teacher, that is with only the help of a supply teacher (and myself), and were not followed up by classroom discussion of the relevant issues. There are however two factors that I believe contributed importantly to the success of these objectives. One was that the relevant ideas themselves were more accessible to pupils, since pupils have a plethora of everyday-life experiences with thermal changes to draw on. Having said this, these experiences, most of which are sensory, are also often misleading and in some cases work as impediments to a sound understanding of thermal change. The project's activities were also very successful in unveiling the misconceptions that might come from these experiences, one of them being, for example, that a block of metal is colder than a block of wood.

The second factor was the use of abstract pictures. Although, the pupils had some difficulties at the start with reading the conventions of the particular abstract pictures showing thermal changes, I believe that their role was paramount in eliciting the accounts I mentioned above. The fact that they depicted two thermometers in the 'Before' and two in the 'After' instance prompted pupils to talk explicitly about the interaction between the system and its surroundings. In particular, the abstract picture of 'a difference in temperature disappears' was used much more often and provoked many more desirable explanations than its counterpart 'a difference in temperature appears' - (I have elaborated on the particular difficulties this latter

picture created to pupils in subsection 7.3.5.3). A similar observation was noted in the discussion of the use of the abstract pictures of ‘spreading out’ and ‘bunching together’ in the previous section (7.6.1). Moreover, the reason given for the poorer use of ‘bunching together’ applies more strongly for the use of the picture ‘a difference in temperature appears’. This is that all the relevant project’s activities that the pupils had done in the classroom put the emphasis on spontaneous processes, and thus focused on the disappearance of a temperature difference and not on its appearance. Another justification is that the pupils met the picture in question for the first time in the context of the interview; it is reasonable therefore to assume, that, despite the fact that the picture was built using conventions the pupils were familiar with, the context of the interview might have rendered its use more demanding.

Year 7 pupils’ accounts of thermal changes often combined a reference to the processes of ‘spreading out’ or ‘bunching together’. Especially in the absence of the abstract pictures, the pupils tended to identify something spreading out or bunching together in warming and cooling changes respectively. (See for example pupils’ explanation of ‘a cold drink left out in the sun’ in section A7.9.5 found in the Appendix.) I take it that these references might allude to some first intuitive ideas the pupils might have about energy. One can certainly easily imagine how, building on these ideas, a teacher could introduce the concepts of energy spreading out in reference to cooling and of energy bunching together (or getting more concentrated) in reference to warming. The challenge there is not as much to help the pupils attain the notion that something is spreading out or bunching together in these changes, but to help them learn how to differentiate between matter and energy spreading out or bunching together. These ideas about energy were pursued by the project in the Year 8 teaching materials.

Finally, as I mentioned at the start of this subsection, one other aim of the teaching materials was that pupils saw temperature differences driving changes of state. The data here are not as conclusive. Anna herself did not seem to emphasise this idea in her lesson; she taught about changes of state in the conventional way focusing only on the nature of the substances before and after the change. This aim was left to be realised by the two corresponding project’s activities, one of which was done in the absence of Anna. There is therefore some evidence in the pupils’ written work that they addressed this issue. However, the analysis of the interviews suggests that this aim was only partially realised, if at all.

7.6.3 Spontaneity and reversibility

- **Did the pupils identify processes that happen easily, but are more difficult to reverse?**

Because the issues of spontaneity and reversibility have an important role in the new approach, it was thought interesting and possibly informing to trace pupils' progress in identifying processes that happen easily, but are more difficult to reverse, even though, strictly speaking this was not an objective of the project's materials for Year 7. The objective set by the materials was rather more limited in scope, that is, that the pupils appreciated that mixing and spreading out processes happen easily ('just happen') whereas their reverse processes 'unmixing' and bunching together do not. Therefore, in this subsection I will be commenting primarily on the progress of pupils' ideas on these issues for a variety of changes, some familiar and other less familiar, based on the data collected in the course of the interviews.

Clearly, the role of the expressions used in the interviews, - i.e. 'it happens by itself', 'someone makes it happen' and 'it is easy to reverse the change' - to elicit the pupils' ideas of spontaneity and reversibility is important in any discussion about the progression (or not) of these ideas. For this discussion in particular, there are at least two reasons for why this role is very important. One reason is that in the absence of any substantive teaching about spontaneous and non-spontaneous changes, the expressions used in the interviews to account for these changes necessarily carried a heavy load of meaning; how the pupils applied these expressions depends a lot on how they interpreted this meaning. A second reason is that there are grounds to believe that at least one of these expressions, the expression 'someone makes it happen', may have inadvertently led pupils to undesirable interpretations of it. (See subsection 7.3.7.1 for more on this issue.)

In the light of these realisations, the data suggest that the pupils' progress in reasoning about spontaneity and reversibility was small and inconsistent. Their tendency on the whole was to resist the idea that a process is spontaneous, or more specifically that it 'happens by itself'. They were very keen to identify an agent, usually a human agent, who is responsible for making the process happen, directly by causing it, or indirectly by setting up the conditions so that it can happen. Consequently, the pupils deemed more easily as spontaneous (i.e. as happening by themselves) changes which did not have obviously agents present, especially animate agents. More particularly, physical changes - especially changes of state - such as 'ice forming on a pond' or 'hot lava from a volcano turns solid' were likely to be characterised as happening by themselves, whereas chemical and biological changes such as 'running and using up food' or 'a baby's bones growing' were less so.

Moreover, situations which make reference to a natural phenomenon, such as ‘water vapour forms clouds’ were often said to be spontaneous. In these cases the expression ‘it happens by itself’ seemed to acquire the meaning of something that is happening ‘naturally’.

A characteristic of this line of reasoning was that the same situation could be seen both as ‘happening by itself’ and as being made to happen by someone, since there is almost always a potential agent, usually a human action, which could be envisaged as participating in the situation. This occurred quite a few times in the first interview, but not as much in the later ones. Moreover, this resistance that the pupils had at first seeing a process as spontaneous seemed to subside in the later interviews. There the pupils were able to identify more efficiently the relevant processes in a given situation (see section 7.2) and thus were able to apply their ideas of spontaneity more accurately and consistently. For example, many pupils could now see that the situation ‘acid rain eroding a stone statue’ referred to the process of erosion which ‘happens by itself’ and not to the event of the creation of acid rain which before was said to involve human activity and thus was seen as needing ‘someone to make it happen’. Another example is ‘wood burning’; the pupils in the later interviews were happy to accept that this situation refers only to the process of burning, which is happening by itself, and not to the action of lighting up the fire. From this perspective pupils’ ideas about spontaneity progressed during the intervention. However, there is no evidence that the pupils at any point related the decision of whether a change happens by itself with what was thought of as happening to the particles and temperature of the system, which is what would have been desirable. Only in their written work, prompted by the relevant project’s activities, did we see pupils making an attempt to do this. So, from this other perspective the progress was minimal.

The use of the phrase ‘it is easy to reverse the change’ by the pupils in the interviews revealed some further issues, this time mainly relevant to their ideas about the reversibility of a change. The application of this phrase to a particular change demands that the pupil identified the change, considered what it means to reverse it, identified the reverse change and finally decided whether this reverse change is easy or not. Interestingly, as pupils became better at identifying the processes involved in a change, they also became better at identifying its reverse change. So especially for some of the physical changes and even for some of the biological ones, especially the ones studied, there was some progress in this respect. What I mean is that the pupils managed to identify and name the reverse process, and even when they did not, showed some appreciation that the identity of the participants of the original process needs to be conserved in the reverse process.

On the other hand, when faced with a change the pupils did not know so much about, they tended to treat it as an 'event', and as a result its reversal seemed to mean little more than stopping this event from happening, or not letting it happen in the first place, or sometimes making it happen again. Other times the suggested 'reverse' change was nothing more than an 'event' which aimed at eliminating the results or products of the original 'event'. Moreover, all these suggested ways of 'reversing' a change implied the intervention at some point of a human action.

Where pupils did not show any progress is at identifying whether it is *easy* to reverse a change or not. Most often the criterion for deciding this was whether the reverse change was humanly feasible, or within a person's control. This criterion was used in both the first and last interviews. Not surprisingly, this finding is very consistent with what was said before about pupils' use of 'it happens by itself'; after all both expressions talk about the spontaneity of a change.

CHAPTER 8

Year 8 Classroom Work

8.1 Introduction

This chapter is the equivalent of chapter 6 for Year 8; it presents the project's teaching materials used with the Year 8 class, and discusses how these were employed, and how the pupils and their teacher responded to them.

In more detail, the rest of this chapter is organised as follows:

- Section 8.2 provides an account of the use of the project's activities in Year 8, based on the observation records taken during their use, the teaching notes that accompany them, and the interview I had with their designer. Its aim is to provide the reader with necessary background information concerning the pupils' experiences in the intervention lessons.
- Section 8.3 discusses the case study of the teacher of the class, based on classroom observation notes, the teacher's written evaluations of the project's activities, and the interview I had with her. This analysis serves two purposes. It provides some further insight into the use of the project's materials in the classroom. Moreover, it is used, together with the case study of the Year 7 teacher (section 6.3) and the findings discussed in chapter 10, to address the research questions concerning teachers, in chapter 11.
- Finally, section 8.4 contains the case studies of six pupils. These trace the pupils' progress across the intervention, based on classroom observations and records of their written work. As such they are used in the discussion of the conclusions for Year 8 (section 9.5), as well as in the discussion of the overall conclusions of the study in chapter 11.

8.2 Project's activities used in the Year 8 classroom

The project's materials and classroom activities for Year 8 introduce to pupils the particle nature of matter; they invite them to pay attention to changes where particles are 'joining' or 'splitting' and to differentiate these from changes where particles are 'mixing' or 'unmixing'. They also require them to look for temperature differences and to identify energy flows due to temperature differences. Energy flows should also be seen as flowing from stores of concentrated energy such as fuel-oxygen systems. These stores are presented as stretched chemical springs; 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. From the project’s perspective activities for Year 8 aimed to work up to the discussion of burning fuels, and thus to the notion of chemical springs; and their order was informed by this aim. Knowledge of chemical change is essential if pupils are to understand the burning of fuels, so the particle pictures which represent what is happening in chemical changes - the notions of joining and splitting are central to these - were introduced first. Another important idea that the pupils needed to know before learning about stores of concentrated energy is that energy flows from places where it is concentrated to places where it is less concentrated, and as they had not done any of the project work on temperature differences in Year 7 they first had to learn that temperature is one kind of measure of energy concentration, or/and that temperature differences cause energy flows. All these ideas were meant to be introduced as part of the first two topics ‘Substances’ and ‘Energy’. There was thought of introducing the body as a steady state system as part of the third topic ‘Health’, but in the end there was not time to do that, as the work on food and fuels carried on until the end of the school year. For the purpose of my study, this work was considered as not belonging to the ‘Energy’ topic, but to a third topic appropriately named ‘Food and fuels’.

I asked Richard Boohan how the project’s activities fitted in each of the topics. (He coordinated their use after consultation with the teacher of the class Beth.) He thought that the project’s activities for the topic ‘Substances’ were not very well integrated into the school’s scheme of work. This referred to activities in the corresponding topic of the ‘Active Science 2’ textbook (Coles, Gott and Thornly, 1989), which, according to Richard Boohan, did not really tie together very well, in the sense that there was no obvious progression or conceptual relation between the activities.

“So, it’s difficult, it’s more difficult to see what the Active Science book is trying to do, and that makes it more difficult for us, in a sense to fit in some activities which have a progression as well.”

In the topic ‘Energy’ the integration of the project’s materials was not very difficult. This was mainly because in the Active Science book the notion of ‘energy’ is not explicitly dealt with - the topic starts off with ‘fuels’ right from the very beginning - and thus there was no conflict between the two approaches.

Finally, Richard Boohan thought that ideally more time should have intervened between looking at temperature differences and energy flows, and looking at fuels, for pupils to assimilate the ideas involved better. Moreover, doing work with

mechanical systems, looking at physical springs and talking about gravitational springs, would have facilitated the move into chemical systems and chemical springs.

Table 8.1 shows the project activities used in the Year 8 classroom and their places in the teaching of the topics ‘Substances’, ‘Energy’ and ‘Food and Fuels’.

Topic	Lesson	Activity
Substances	1	C4 Objects and substances
	2	F2 Wearing out
	3	G1 A ladder of sizes G2 Using the ladder of sizes
	4	F1 What are substances like?
	6	F3 Different kinds of change (renamed: Substances and changes)
	8&9&10	F5 Matching changes (renamed: Everyday changes)
	13	G3 Heating copper G4 What happens when new substances are made?
Energy	16	G5 Joining, splitting, mixing and ‘un-mixing’ G6 Joining, splitting, mixing and ‘un-mixing’ - some examples
	1	E1 Concentrated energy
	2	E2 Energy on the move E3 Energy transfers in the kitchen
	3	E5 Insulation
	4	E6 Examples of insulation E4 Getting hotter and colder E7 Energy from hot to cold
Food and Fuels	4	B6 Inventions
	5	B7 Making an engine H1 Things that ‘just happen’ and things that don’t
	6	H4 Ways of storing energy
	7	H5 Fuels and food

Table 8.1 Project’s activities used in Year 8 and their places in the topics

8.2.1 Topic: ‘Substances’

8.2.1.1 ‘Objects and substances’ (Activity C4)

This activity was used in the first lesson of this topic. Its aim was to *“provide a starting point for a discussion of the idea of ‘substance’ and to distinguish this from ‘object’”* (Boohan, 1996a - Theme C, p4)*.

Before introducing the activity Beth invited the pupils to suggest what the word ‘substances’ mean and prompted them to give her examples of substances one finds at home. She also defined the term ‘element’ as a pure substance and said that a ‘compound’ is more than one element joined together. The teaching notes for the activity suggest that these two terms could appropriately be discussed in relation to it. For the activity the pupils had to cut up a list of twenty things, sort them into ‘objects’ and ‘substances’, and then match each object with the substance it is made from. Beth read out the instructions and told them that they should make sure that they knew the difference between ‘objects’ and ‘substances’ before they attempted to sort out the list. She further asked them to suggest examples of objects.

The pupils worked in groups. Considerable discussion was produced in the groups when the pupils realised that there were many possible combinations between the objects and the substances - one object could be made from different substances. At the end all their answers were checked.

The ‘Objects and substances’ activity was followed by a practical where children had to look at different substances and sort them into three or four groups. Beth prompted them to use the concepts of ‘mixture’, ‘substance’ and ‘object’ in thinking about how they would group them. She later suggested that possible categories for grouping might be: ‘mixture’, ‘solids’, ‘liquids’, ‘smelly’ and ‘bendy’. After letting them do the activity in groups Beth collected and discussed their answers on the blackboard.

* As in chapter 6, in the interest of brevity, hereafter every quotation from the project’s teaching notes will be referred to as (Theme X, pY), that is using the letter of the corresponding theme in the publication (Boohan, 1996a) and the number of the page (of this theme) in which the quotation appears.

8.2.1.2 'Wearing out' (Activity F2)

"The activity makes the distinction between changes to objects and changes to substances, as a way of introducing the essential nature of a chemical reaction" (Theme F, p3).

This activity took place in the second lesson of the topic, following a practical in which the pupils were given few substances and were asked to find out what happened when they mixed some of them. Among other things, they were asked to decide whether a new substance was made in each case. Pupils working in groups were puzzled about what criteria to apply in deciding whether a new substance was made out of the mixing of two other substances. However, no classroom discussion on the issue followed the investigation and thus they did not have the opportunity to clarify their ideas.

Coming to the project's activity, Beth explained the conventions used in the pictures in the worksheet, and told the children what they had to do. They had to group ten changes in two groups according to whether they are mechanical or chemical changes, that is according to whether a new substance is made or not. The worksheet also asks pupils to look at the changes in each of the groups and think about whether it is possible to get the object or substance back to the way it was at the start, how this could be done and if it would be easy or difficult. Beth did not give any guidance to the class about how to answer these questions, and as a result most of the pupils seemed to ignore them.

The activity was done by pupils in groups and tied very well with the preceding practical investigation.

8.2.1.3 'A ladder of sizes' (Activity G1) and 'Using the ladder of sizes' (Activity G2)

Both of these activities were used in the third lesson in the topic. The first one aims to *"give pupils experience in thinking about the relative sizes of things, especially those things which are too small to be seen with the naked eye"* (Theme G, p3). In the second one, *"pupils use the ladder of sizes to work out the relative sizes of things"* (Theme G, p4).

Beth first showed the pupils a series of slides of objects of different sizes, taken from the book 'Powers of 10' in the Scientific American Library series (Morrison and Morrison, 1982). She then gave them the worksheets of the first activity and stressed that it was important that they read the information provided, on very small things. The pupils had to cut up eighteen pictures of objects and place them in order of size.

Once they had checked their answers, they could write them up next to the ladder of sizes provided on the worksheet.

Having constructed the ladder, the pupils were asked, in the second activity, to compare differences in the sizes of things. Beth explained to them what they had to do and read out the example that was given on the worksheet. Most pupils, however, did not have time to finish the second activity and took it home to do.

8.2.1.4 ‘What are substances like?’ (Activity F1)

“The activity introduces pupils to the ‘particle pictures’ [...], and the arrangements of particles in a variety of substances” (Theme F, p3).

This activity was used in the fourth lesson in the topic. Beth introduced the conventions of the abstract pictures by inviting pupils to suggest what these may represent and to give examples of such substances. She then went on to talk about the abstract pictures of the activity ‘Different kinds of change’ (later renamed ‘Substances and changes’, Activity F3) which represent different kinds of changes (mechanical changes, changes of state and chemical reactions). In both cases she insisted that they understood the representations of the three states of matter and that change in their shading meant change of substance.

For the activity the pupils had to match each of twenty examples of substances to the picture (nine in total) that showed the arrangements of its particles best. The fact that the matches would be best matches and not necessarily exact was not stressed by Beth. The activity was worked in groups and prompted a lot of discussion about what solids, liquids and gases are and about which substances are pure and which are mixtures. At the end of the lesson Beth collected and discussed the pupils’ answers on the whiteboard.

8.2.1.5 ‘Different kinds of change’ - later renamed ‘Substances and changes’ (Activity F3)

This activity was used in the sixth lesson. It followed a lesson on ‘acids’ in which the pupils had tested for the acidity of different liquids.

The activity was intended *“to encourage discussion about the differences between various kinds of changes, and to give pupils experience in thinking about changes in terms of particles” (Theme F, p4).* Beth reminded the pupils of the meaning of the abstract pictures, which she had introduced together with the ones of the previous activity of the project. The pupils had to match each of fourteen changes to the picture (six in total) that best showed what happened to its particles. It was done as

a group activity giving rise to interesting discussion about what constitutes a change of substance. The pupils' answers were not checked.

The next lesson was on 'alkalis'; the pupils had to do an investigation and rank various substances in order of alkalinity.

8.2.1.6 'Matching changes' - later renamed 'Everyday changes' (Activity F5)

This activity was done over nearly three lessons, the eighth, ninth and tenth in the topic. In it pupils are encouraged to look for "*what is essentially similar in superficially different changes [...] with the support of particle pictures*" (Theme F, p5). This is considered by the project important for understanding the nature of changes.

The activity was in two parts. The first part was intended as a poster activity, but was done as a group activity. As before, the pupils had to match a set of (twelve) changes to a set of (ten) particle pictures and write a reason for each match they made. Not all pictures had a match, whereas some had more than one change matched to them. For the second part the pupils had to compare four pairs of selected changes and identify one similarity and one difference between them. What was hoped for in this second part of the activity was that by focusing on the particle pictures, pupils would be helped to make abstractions and pay less attention to superficial features of the changes.

Interesting discussions took place in some groups about the nature of some substances and about whether the changes produced new substances or not. However, at the end of the first lesson very few pupils had finished the first part of the activity and Beth commented that for almost half of the pupils it had proved very difficult.

In the two following lessons, the pupils continued working on parts one and two of the same activity. The fact that the intended matches were best matches and not exact ones gave rise in some cases to lots of hesitations and changes of opinion. Beth insisted that the pupils wrote reasons for their choices and encouraged them to make use of words like substance, mixture, solid, liquid, gas, shape, new, particles, melting, same. Only some of the answers for the first part of the activity were discussed collectively in the classroom; no mention was made of the second part of the activity although by the end of the third lesson most pupils had attempted it. After the pupils had finished working on the activity, Beth suggested that they enriched their knowledge about acids and alkalis; to that effect some chose to read and copy in their books the corresponding sections from either one of the two

textbooks ‘Starting Science 2’ (Fraser and Gilchrist, 1986) and ‘Integrated Science 2’ (Bethell, Coppock, and Pebworth, 1991).

8.2.1.7 ‘Heating copper’ (Activity G3) and ‘What happens when new substances are made?’ (Activity G4)

These two activities were used in the thirteenth lesson in the topic. The previous two lessons were devoted to practical work. In one the pupils extracted copper by electrolysis of copper sulphate, which they had previously produced by reacting copper oxide with sulphuric acid, and in the other they heated copper strips to see what happens. For both experiments they had to make a results table mentioning what they had done and what they had observed. In the context of the second experiment Beth talked of copper joining or combining with oxygen to produce copper oxide which was a new substance. The existence of heat or fire was said to be vital for the reaction to take place. However, my impression was that some children perceived fire as the cause of the change, rather than as a mere facilitator.

The purpose of the two project activities mentioned above is *“to introduce the idea that when substances react to form new substances, particles do not appear or disappear but join together in new ways”* (Theme G, p4).

For the ‘Heating copper’ activity the pupils needed to choose the picture which best showed what happens when copper is heated in air and to write why they had made this choice. For each of the remaining five pictures they had to explain what it showed and why they had not chosen it. Beth chose one picture and checked that the whole class understood what it showed and what they had to write about it. The rest of the activity was done in groups. The issue that seemed to arise was whether the oxygen reacts with all the copper or only with its surface.

In the ‘Heating copper’ activity changes to substances are represented in the pictures as if completely new particles were being formed; it is the following activity, ‘What happens when new substances are made?’, that introduces pupils to the idea that in a chemical reaction new substances are formed as the particles join together in new ways. A new kind of particle picture is introduced to capture this idea. Furthermore, based on this definition a chemical change is distinguished from a mixing change, as in the latter the particles do not join together. Beth presented these ideas to the pupils with the aid of the transparency that accompanies the activity, without giving any emphasis to the new kind of particle picture used in the worksheet. The pupils had to find, in a similar way to the previous activity, which of these new pictures represented best what happens when copper is heated in air. They worked in groups;

the discussions that took place centred around what the pictures were meant to show. The majority of the pupils carried on doing the activity into the next lesson.

Other lessons:

In the next lesson Beth was absent, but had prepared a worksheet for the pupils to do. On it there was a list of sixteen changes; the pupils had to look into science textbooks to find out as much as they could about each of them. They then had to write down this information, use the ideas they had previously met to explain it, and finally, they had to draw a picture of the change. The aim had been that the pupils would familiarise themselves with these changes - some they had already experienced as practicals - so that they could later identify what happens to the particles in them. However, most pupils, as I already mentioned, carried on working on the project's activity 'What happens when new substances are made?' from the previous lesson and did not do this latter activity.

In the following lesson, Beth talked to the class about the changes 'rusting' and 'getting iron from iron ore' and discussed with them whether in these changes new substances were formed by particles joining or splitting. She then asked them to consider the same question for seven of the changes in the list. The lesson ended with the pupils doing a quick experiment heating some iron powder to see if there is any colour change.

8.2.1.8 'Joining, splitting, mixing and 'un-mixing'' (Activity G5) and 'Joining, splitting, mixing and 'un-mixing' - some examples' (Activity G6)

These activities were used in the sixteenth lesson in the topic. The first one, 'Joining, splitting, mixing and 'un-mixing'', is not so much an activity; it introduces four pictures showing substances mixing, joining, 'un-mixing' and splitting and provides four sets of them to be used as resources for a 'case-study' approach; *"when pupils come across a change of one of these types they can cut out one of the pictures and stick it in their books"* (Theme G, p6). The second activity is a matching activity; *"it gives pupils further practice in identifying what happens to the particles in a range of different kinds of changes"* (Theme G, p6).

It was agreed that as Beth was absent I would introduce the pictures of the first activity to the pupils. I did so stressing the differences between the 'joining' and 'mixing' pictures and the 'splitting' and 'un-mixing' ones respectively. For the second activity, I gave the pupils a sheet with twelve examples of changes which they had to cut and match to the 'joining', 'mixing', 'splitting' and 'un-mixing' pictures. The worksheet provided some information about each of the changes, to

help the pupils to find an appropriate match. The pupils were also expected to write about the reasons they made the matches. I found on the whole that the pupils needed a lot of help with the activity, but also that by the end of the lesson some of them had got an understanding of what was all about.

Other lessons:

In the following lesson the class studied experimentally the reaction of iron with sulphur. The pupils were asked to look for and identify instances of ‘joining’, ‘mixing’, ‘splitting’ and ‘un-mixing’.

Finally, in the two last lessons of the topic ‘Substances’ the class did two practicals: one on rock salt separation and one on the electrolysis of water. Apparently the second one was not successful.

The end-of-the-topic test consisted of three papers; one was prepared by the project and the other two were tests from GASP (Graded Assessments in Science Project) (Swain, 1988; ULEAC, 1992).

8.2.2 Topic: ‘Energy’

8.2.2.1 ‘Concentrated energy’ (Activity E1)

Beth started the first lesson on this topic by collecting the children’s ideas on energy. She then went on to use the project’s activity called ‘Concentrated energy’. *“The aim of this activity is to introduce the notion that we can think of a ‘concentration’ of energy in the same way as a concentration of a substance”* (Theme E, p2).

Beth introduced the ideas of ‘spreading out’ and ‘bunching together’ to describe changes in concentration, using the transparency that accompanies the activity alongside a simple demonstration. In this she diluted a drop of purple dye - potassium permanganate - into a beaker of water to show the dye ‘spreading out’ into the water. She then talked of energy spreading out and becoming less concentrated and exemplified this for a red-hot nail put in a beaker of cold water. Finally, Beth discussed with the children the fact that a ‘spreading out’ process happens more easily forwards than backwards, and that consequently it is hard to get the purple dye or the energy to become again more concentrated.

On the project’s worksheet there were two activities for the pupils to do. For the first they had to dilute repeatedly a coloured liquid until they could no longer see it and for the second they ‘diluted’ hot water with cold until they could no longer notice the temperature changing. For both activities they had to answer some questions which aimed to make the point that even though matter and energy spread out, they do not

disappear, even when they have spread out so much that they are undetectable. The activities proved rather straightforward for the pupils who did them individually or in pairs.

8.2.2.2 ‘Energy on the move’ (Activity E2) and ‘Energy transfers in the kitchen’ (Activity E3)

These two activities of the project were used in the second lesson of the topic. ‘Energy on the move’ is intended to be used as a classroom activity; it consists of three transparencies which introduce the abstract pictures of thermal energy flows to be used throughout this and the next topic. Beth discussed the conventions used in these abstract pictures with the whole class. The pupils did not spontaneously reason that a beaker of hot water cooling down will become the same temperature as the room around it, nor did they see at first that in an ice cube melting in a room the energy transfer is from the room to the cube and not vice versa.

Then Beth gave them the second activity ‘Energy transfers in the kitchen’ to do. In this activity *“abstract pictures are used to represent some everyday examples of energy flow from hot to cold”* (Theme E, p4). The pupils had to choose the pictures they thought best represented the four given changes and stick them in the spaces provided in the worksheet. Beth drew the pupils’ attention to the fact that some of the pictures were ‘impossible’ because they showed energy flowing from cold to hot. Some pupils worked individually, some in small groups. After they had finished with the activity Beth discussed with them in depth about the energy changes involved in two of the situations.

8.2.2.3 ‘Insulation’ (Activity E5)

This activity *“gives pupils practical experience in looking at the effect of insulation. More importantly it encourages them to think about how the idea of energy flow due to a temperature difference can be used to explain the phenomena”* (Theme E, p5).

The pupils experienced the following experimental situations: they had a tube containing water at 20°C, which they put into water at different temperatures - higher, the same and lower - first with and then without insulation. For each situation they had first to predict what the temperature might be after two minutes, check their predictions and write the conclusions they could draw from the results. They then were asked to interpret the situations by thinking about the direction and relative sizes of the energy flows due to temperature differences. In particular, they were given a set of pictures which represented the situations they had experienced, and had to draw arrows on these pictures to show what is happening to the energy. They

finally had to describe what each of their choices was showing. Jon, a student teacher who gave the lesson on that day, collected and discussed the pupils' answers with them.

Commenting on the activity Beth said that the pupils had not had much prior experience of predicting temperatures and using insulation; there were many pupils who did not know how much insulation they should put and who predicted that the temperature of the insulated tube will increase when put into a beaker of water at room temperature. She reported that the majority of pupils had managed the second part of the activity with only little help.

8.2.2.4 'Examples of insulation' (Activity E6), 'Getting hotter and colder' (Activity E4) and 'Energy from hot to cold' (Activity E7)

These activities were used in the last lesson of the topic. The first builds on the previous practical activity 'Insulation' *"by relating the ideas of energy flow and insulation to more familiar everyday examples"* (Theme E, p5). It is a matching activity; pupils match situations involving insulation to abstract pictures of energy flow.

The pupils worked in groups. Beth had asked them to talk about the changes in groups and to have their matches checked before they stuck them in their books. The matching of the situations 'snowman on a freezing day' and 'water pipes on a cold day in winter' proved most contentious and created interesting discussions in the groups.

The activity 'Getting hotter and colder' was intended *"as a stimulus to discussion about what happens in various situations in which there are temperature differences"* (Theme E, p4). For each of six changes two pictures were given; the pupils had to identify the picture that came first and write about the reasons for their choices. It was done as a group activity; the pupils' answers were not discussed collectively.

Finally, the last activity 'Energy from hot to cold' was given to the pupils as homework. In this activity pupils are first asked to circle the correct words in a piece of text about energy flow from hot to cold. They then have to write their own explanations for six different phenomena. *"It is intended that the 'circling' activity will provide a prompt for the kind of explanations which are appropriate"* (Theme E, p6). No instructions were given by Beth for this activity.

8.2.3 Topic: 'Food and Fuels'

In the first three lessons in this topic pupils investigated energy in food and fuels. More precisely, they measured the temperature differences that a peanut and different fuels produced when burnt. They also did an experiment in which they tested whether a leaf has starch. Finally, they talked about power stations and how fuels are 'made' into electricity.

8.2.3.1 'Inventions' (Activity B6)

The first project activity for this topic was used in the fourth lesson. The activity *"introduces a time scale for inventions, in order to put some important inventions in context"* (Theme B, p5).

The children had to put a list of twenty inventions in chronological order so as to match them to a given time scale. The correct answers were given to them at the end of the lesson. The point this activity tries to make *"is that while fuels have been used for many thousands of years to make things hot, only more recently have they been used to make things move and even more recently to generate electricity"* (Theme B, p5). Pupils are prompted to think about this point by two questions at the bottom of the worksheet. The pupils in Beth's class however were not directed to answer these questions and thus this point was not made.

8.2.3.2 'Making an engine' (Activity B7) and 'Things that 'just happen' and things that don't' (Activity H1)

The project activity 'Making an engine' *"introduces the idea that a temperature difference can be used to make something move"* (Theme B, p6) and was used in the fifth lesson in the topic.

The first part was a simple experiment the pupils had to do using a temperature difference to drive a 'model' engine. They did this in groups and explained in writing what they observed. Beth encouraged them to identify the energy transfers taking place using ideas about the energy being more concentrated and spreading out. Another science teacher who was assisting with the lesson demonstrated a small steam engine and explained how it worked. Beth talked about the fuel being a store of concentrated energy and discussed with the children the similarities between the steam engine and the 'model' engine they had made. She also talked about power stations and explained how electricity is made.

The second part of the activity which attempts to make the point *“that bigger temperature differences can do more - they are better for making things move”* (Theme B, p6) was not done.

The activity ‘Things that ‘just happen’ and things that don’t’ was partly introduced in the same lesson but was only finished in the following. This activity *“introduces the idea of spontaneous and non-spontaneous changes. Spontaneous changes are those that ‘just happen’ by themselves and are able to drive other changes which do not ‘just happen’ by themselves”* (Theme H, p4). Beth introduced these ideas with the aid of the transparency prepared by the project for this purpose and further linked them with the ideas met in the previous activity and in the context of the steam engine demonstration. For the activity the pupils had to match six changes to the pictures that represented them best. These were changes of warming and cooling, and of starting to move and stopping. The activity did not present any difficulties to the majority of the pupils.

8.2.3.3 ‘Ways of storing energy’ (Activity H4)

This activity was used in the sixth lesson in the topic. In it a set of new pictures show energy being stored and released during chemical change. Beth introduced these new pictures, using the transparency that accompanies the activity. The essential idea in this activity *“is that energy can be stored by making molecules move faster or by splitting molecules apart”* (Theme H, p6). The activity exemplifies this idea for one ‘case-study’; it looks in detail at how energy can be stored in water. Beth talked briefly about the two ways of storing energy in water and demonstrated one by electrolysing water to form hydrogen and oxygen, which when made to join again produced a loud bang strongly suggesting that energy was released.

In the worksheet the pupils were asked to write about the changes and the explanations for them that were discussed on the transparency. Work on this activity continued in the seventh lesson in the topic.

8.2.3.4 ‘Fuels and food’ (Activity H5)

In this seventh and last lesson, the class revised the ideas and pictures of spontaneity met previously and discussed the pictures which show the different ways of storing energy. Only one of the project’s activities remained for them to do. This *“develops from the way of thinking about fuels introduced in the previous activity - ‘Ways of storing energy’ - and extends the range of examples”* (Theme H, p7).

As in other similar activities, the pupils had to match a set of ten changes in which energy is being stored or released to a set of pictures. The situation ‘a plant makes starch by photosynthesis’ proved the most difficult to match as children seemed not to know many things about the process of photosynthesis. Unfortunately, there was no time left for the answers to be checked and discussed.

8.3 Case study of Year 8 teacher: Beth

Beth was the head of science in the school where I conducted my field work, and the science teacher of the Year 8 class I worked with. She is a very dynamic and vivacious person always on the move as she tries to juggle around her different responsibilities. In the classroom she moved briskly and efficiently and the pitch of her voice betrayed her full emotional as well as physical commitment to her job. She thinks that science is interesting and always talked with affection and concern about her pupils.

What did she think the project is about? She saw the project as providing the teachers with a coding system consisting of a combination of pictures and words which, when used systematically in the classroom to describe changes, will stimulate interesting discussions amongst pupils, enhance their abstract thinking, and therefore in time raise their achievement. Just like Anna, Beth appreciated each activity or set of activities on their own merits; she saw them as working together only at the level of promoting deeper understanding and more abstract thinking, but not to build up a coherent account of the Second Law of Thermodynamics. However, she also recognised that apart from being a different approach to teaching certain things, it introduces new ideas as well.

“The business of one change driving another, I think is a new idea largely. [...] It shouldn’t be a new idea looking back, but it is a new idea for that age group I think.”

“What you’re doing is you’re trying to access the information and then getting them [the pupils] to go a little further to internalise it at an earlier stage. So I think that is new.”

For her the project provided the pupils with a simple pictorial way of expressing abstract ideas, it gave them something “to hang their words onto”, it gave them “a discussion point” and promoted interaction both at the level of the whole class and at the level of the group. According to her, it particularly increased the self-confidence of pupils with language difficulties, since they could express themselves through the choice of pictures. Beth also thought that the project gave the teachers a set of communication tools with which they could talk about complex changes and get “a common understanding”, on which they could build later on. These communication

tools included a set of simple words that teachers could use consistently. Beth acknowledged the problem that some of these words were often used loosely as analogies by teachers, whereas the project had given specific meanings to them, but said that:

“...to some extent that’s easier to get your head round than the many different ways that you might use them.”

She was concerned that because these words carry a lot of meaning, when pupils use them one might easily, but wrongly, assume *“that they understand what the whole package means”*.

Another concern of hers was that, because the new approach involves so much learning about conventions, the pupils can easily be left behind and get alienated if they happen to be absent for a couple of lessons or more.

Beth welcomed the use of the project’s materials in her lessons and easily accepted the suggestions Richard Boohan made about how these could fit in the existing schemes of work for the three topics chosen. However, being a teacher who puts a lot of emphasis on practical work, she expressed regret that the pupils had not done more practical activities.

“It’s been a bit daunting for some because you have so many to match up and they go oh no ...not pictures again ...oh no ...and you’re just beginning to think oh we could just do without this, let’s have a practical, can’t we do a proper experiment for once. I suppose it’s being unrealistic in that respect. They haven’t done as many practicals as I would normally have done with a Year 8 group and I’ve expected far more consolidation from them than I have often expected from previous Year 8 groups.”

She seemed very at ease about my presence in the classroom. Because of her multiple responsibilities she never had time to speak to me after the end of the lesson, but we exchanged some feedback occasionally during the lessons. As could be expected, the more the materials were unfamiliar to her the more she referred to me. Furthermore, on two occasions she asked me to introduce the materials to the class in her absence.

The vocabulary used in the Year 8 materials did not seem to present any problems to Beth. Maybe at the start she used the term ‘joining’ quite loosely to mean mixing as well, but later on she adhered to the use suggested by the project.

Since one of the topics I observed her teaching was the ‘Energy’ one, a topic of special importance to the project, I paid particular attention to how Beth made use of the terms involved. Therefore, I could not help noticing that she extensively used the idea of energy forms, her examples of them ranging from heat energy to human

energy. This is important because one of the principles of the approach is not to talk in terms of forms of energy, but that energy should be viewed as one thing which can be more or less concentrated and can flow. Moreover, Beth's use of the words 'temperature', 'heat' and 'energy' was not always so desirable; she occasionally appeared to use them carelessly and without discrimination. She would say, for example:

"The hot oven gives energy to the room. They both end up with the same energy."

or

"The heat is going to be given to the metal block."

From the new approach, the idea she found more interesting is that one can make something happen by coupling it to a spontaneous change.

"I found it very interesting particularly the idea of one change driving another. I found that very interesting and sorting out ideas... for myself."

However, she expressed the fear that not many teachers would use the activities that include this idea in the future.

On the whole, the abstract pictures did not seem to present any particular problems to Beth with the exception perhaps of the ones used to represent chemically stored energy; these seemed to overwhelm her a little. Moreover, although she praised the abstract particle pictures, she moved between macro and micro interpretations of them rather carelessly. For example, for the picture which shows gas trapped in a solid, she accepted / offered the suggestion that it may represent a 'brick' or 'cheese', and for the picture which shows liquid with pieces of solid of a different substance inside, she suggested the example of ice cubes in water.

In teaching the abstract pictures Beth took care to repeat their conventions to the pupils whenever she could, though she never spontaneously used them herself to explain or describe a change. As already mentioned, she argued that she had forced too many pictures on the children who should have had more practical experiences before being introduced to them.

Another thing that Beth did not do was to encourage pupils to look for similarities between different changes.

Otherwise, I found that Beth used the project's materials efficiently. She took care that the pupils completed the activities by providing more time for this when she felt that it was needed. She always encouraged the pupils to follow the instructions given on the worksheets about the tasks and to work in groups. Moreover, she almost

always checked pupils' responses to the activities in end-of lesson whole class discussions. This, I believe, was very beneficial for the children who were thus given a chance to raise points for discussion and clarification. Finally, conducting practical activities with the class was perhaps Beth's strongest point; she was undeniably very successful in smoothly tying in practical work with the ideas of the project.

To sum up it can be said that Beth provided sound conditions for the use of the project's materials. It may be true that in principle she could have further exploited their use and that she could have better followed up the opportunities that arose from them; however, due to the nature of the development of the curriculum materials (see also Anna's case study in section 6.3), Beth had to make use of a set of difficult materials at a short notice, and in my view she managed this very adequately.

8.4 Year 8 pupil case studies

Almost all the project's activities for Year 8 were done as group activities. As a result of this it was expected that the pupils who worked in the same group would give similar answers. Indeed, in some cases it happened that all the members of a group had identical answers - including justifications for choices made. Following from this observation I decided that for the analysis of the Year 8 class it would be more sensible to examine the progress of pairs of pupils working together instead of individuals as in Year 7.

Another difference with the Year 7 case studies is that detecting the pupils' progression in the ideas met in Year 8 was not as easy. This was because although the new ideas were taught in a logical order, in the sense that those met in the first two topics (i.e. about the nature of chemical change and about energy flows due to temperature differences) were essential for an understanding of the ideas introduced in the third topic (i.e. about the burning of food and fuels) (see section 8.2 for discussion of sequence of activities), they seemed to be more self-contained in their respective topic and rarely re-appeared (explicitly) in the activities of the other topics. Thus, in the following accounts the development of a pupil's understanding is seen mainly as happening in the period of one topic and not so much across topics.

8.4.1 Naomi and Rebecca

Naomi was a pupil of above average achievement whereas Rebecca was of average achievement. Though the difference in academic performance was not big, there was a considerable difference in their confidence and self-assertion, and this was reflected in the way they worked together. Naomi seemed to dominate the discussions and often dictated the answers for the whole group to write. In the

classroom they were both very active and willing to participate. They always sat together and got along very well. Occasionally, they would get very noisy, chatting and laughing about things not related with the lesson. I got the impression that Beth thought highly of them, and particularly of Naomi. Their books were very neat and tidy and their writing was of a good standard. In them one could find, apart from their answers to the activities and their accounts of the experiments they had done, extended pieces of relevant encyclopaedic knowledge (e.g. information about copper, acids, alkalis, acid rain etc.), which they had taken the initiative to access and copy.

Both Naomi and Rebecca worked well with the project's activities, although Rebecca left a number of them incomplete. Naomi's written explanations were most often rich and extended, whereas Rebecca's were shorter but nevertheless addressing the main points. Naomi was also more eager to participate in the interviews. Their performance in the interviews did not match the expectations I had formed based on their performance in the classroom; their newly acquired ideas did not seem to hold as strongly in the less structured setting of the interviews.

Changes to matter

One of the objectives of the project's materials was to introduce the pupils to the particle nature of matter; more specifically, the pupils were taught to differentiate between changes where particles are 'joining' or 'splitting' and changes where particles are 'mixing' or 'unmixing'. How did Naomi and Rebecca cope with these ideas?

At the beginning of the topic 'Substances' Rebecca did not know the difference between a 'substance' and an 'object'. Naomi on the other hand when asked to give an example of a substance which is solid with trapped air in between the particles, offered 'a cooker', which suggests both that she did not always hold clear the difference between a 'substance' and an 'object' and that she interpreted a picture showing the arrangements of particles in a macroscopic way. Moreover, they both found difficulty in identifying a change of substance; the main criterion they seemed to use to decide whether a substance had changed was to look for changes in its physical properties. So 'steam' was said to be different from 'water' "*because you cannot drink it*". However, a couple of lessons later when Naomi was called to decide whether the situation 'blood forming a blood clot' involves a change of substance (see activity 'Matching changes' later renamed 'Everyday changes', F5, 'Substances', 8.2.1.6), she told her friends that the important question to answer was whether blood changes into a different substance in the process, and not whether it just changes colour. Another couple of lessons later she wrote about it:

“When blood, which is a liquid, comes out of your body it is fresh. But when it dries up it is not as fresh as it was. It is affected. And it is a solid.”

It is probable that by the word ‘affected’ Naomi implied that the substance had undergone a change.

The identification of the state of some substances was not always straightforward. Discussions arose about the state of ‘dust’, of a ‘stain’, of ‘ice’, of ‘petrol’, of a ‘sponge’ and of ‘toothpaste’. Rebecca originally thought that ‘dust’ cannot be solid because *“you cannot pick it up”*; Naomi reasoned that ice has water and gas inside, and petrol was said to be liquid and gas. It seemed that Naomi believed that if a substance can change state, it is because it includes it all along.

Another difficulty they faced was to differentiate between the ideas of ‘mixing’ and ‘joining’, and of ‘unmixing’ and ‘splitting’. Naomi seemed to believe at the start that *“there is always a new substance when you mix two chemicals together”*. This was challenged in the subsequent teaching. In the activity ‘Matching changes’ - later renamed ‘Everyday changes’ (F5, ‘Substances’, 8.2.1.6) - although the pupils had not yet been introduced to the pictures of ‘joining’ and ‘splitting’, ‘mixing’ and ‘unmixing’, they were asked to differentiate changes of dissolving from chemical changes between a solid and a liquid. The attempts failed; the chemical changes ‘putting Alka Seltzer in water’ and ‘using bleach to get rid of a stain on clothing’ were matched to the picture that represented dissolving, and the dissolving change ‘washing dirt off your hands’ was matched to the picture that showed a chemical change. However, what is also interesting here is the way Naomi attempted to justify these two different kinds of changes. For the situation ‘using bleach to get rid of a stain on clothing’ she wrote:

“The stain which is solid and the bleach which is liquid are mix, but the stain becomes a liquid separate from the bleach.”

whereas for the situation ‘washing dirt off your hands’ she explained:

“The dirt is solid and the water which is liquid mixes with it and it becomes a dirty and affected water.”

I take her attempt to account for the process of dissolving to be desirable, in the sense that it is in the right direction; in her own words she tried to explain how the two substances mix but do not react. At that point she had adopted a different criterion to decide whether two substances mixed together form a new substance. When I asked her about it, she said that it depends on the substance that gets dissolved,

“if it dissolves it makes a new substance, if it doesn’t, like oil and water, it doesn’t make a new substance”.

Rebecca's answers for the same activity were on similar lines only less elaborate.

A little less than three months later, at the test at the end of the topic 'Substances', Naomi was still not very sure to which pictures to match the changes 'dissolving some instant coffee in water' and 'dropping acid onto limestone to make a gas'. In her first attempt she matched them incorrectly as she had done in the 'Matching changes' activity, but then corrected the matches and wrote about them:

"Water is a liquid and the instant coffee is the solid. When they are mixed they give black coffee which you drink."

Acid is liquid, limestone is solid. The acid and the limestone are mixed. They react. They become a liquid but gas comes out of it."

From these explanations we see that by the end of the topic she could make a distinction between 'mixing' and 'reacting'. Whether she still maintained at the same time the belief that if a substance fully dissolves then it becomes a different substance, is not very clear. In another answer she gave in the test she wrote about copper sulphate solution: *"Copper sulphate is a solution which means it is joined"*, which rather suggests that she may have been still hanging on this idea, even though it seems to contradict her match of 'dissolving some instant coffee in water' among other things.

Rebecca, made the right matches for the above changes, first time round; she, however, made no mention of the fact that acid reacts with limestone and they make new substances. Instead she described the change with the words *"it melts and gives out a gas"*.

What we see in the above quotations is not trivial. The pupils agonised over using the terms 'dissolve', 'mix', 'melt', 'react' and 'join' correctly. Most of these terms are used in everyday talk much more loosely, whereas as scientific terms they bear very exact definitions and uses. Pupils have to master these; the above extracts show us something of the path of learning they follow.

Once they knew how to distinguish between 'mixing' and 'joining' they could also distinguish between 'unmixing' and 'splitting'. Again in the end-of-the-topic test Naomi chose the picture of 'unmixing' as a match for the change 'purifying rock salt'. This was a change she had experienced as a practical in her lessons, and she conveyed this extra knowledge when she wrote about it:

"Rock salt has things inside which are not joined. They are mixed. So when you purify the rock salt your water evaporates leaving pure salt."

Rebecca on the other hand wrote more plainly:

"The salt is a mixture of something and then it is separated."

With the burning changes they faced no problem, although they were sometimes more inclined to see the fire as causing the chemical change than the reaction of the substance with oxygen.

Overall, my impression is that by the end of the topic both Naomi and Rebecca managed to differentiate between ‘mixing’ and ‘joining’ changes and their opposites well enough; they still found it difficult to account for the changes in microscopic terms, but they used the terms progressively more correctly and in more difficult contexts, although not always spontaneously.

Temperature Differences and Energy Flows

Another objective of the materials used with the Year 8 class was to teach pupils to look for temperature differences and identify energy flows due to temperature differences.

The first question here is what Naomi and Rebecca understood by the term ‘concentrated energy’ used by the project as equivalent to ‘temperature’. It appears to me that whereas they understood that something which is hot has a high concentration of energy, Naomi specially also thought that it has lots of energy. This appears very clearly in the following quotation where Naomi explains what happens when a hot boiled egg is cooled down by putting it in cold water (see activity ‘Energy from hot to cold’, E7, ‘Energy’, 8.2.2.4):

“When a hot egg which contains a lot of energy is put in cold water which has very little or no energy, the energy from the hot egg goes into the cold water making it warmer. The egg and the water become the same temperature and afterwards it goes into the same temperature as the room.”

Here, although she identified a flow of energy and she acknowledged that at equilibrium there is no temperature difference between the system and the surrounding, she attributed this flow to a difference in energy between the system and its surroundings by using the term ‘energy’ interchangeably with that of ‘temperature’.

Another example shows more explicitly how more concentrated energy meant more energy for Naomi. Moreover, as a consequence it is not clear whether she saw insulation as reducing the amount of energy flow and not the rate of energy flow:

“At the start the object which has not object surrounding it is the warmer temperature than the room, which means it is more concentrated and the more concentrated the more energy. So the more energy from the object is flowing to the room and eventually it becomes the same temperature as the room. In B it is the same as A except it is an object surrounding an object. This is called.... So little

energy is flowing from the object into the room. Eventually it comes to the same temperature as the room."

Most of Rebecca's activities on this topic were left incomplete. She made much less use of the term 'concentrated energy', while she often used the idea that energy spreads out from hot to cold. Similarly to Naomi she occasionally used the terms 'temperature' and 'energy' without discrimination, to the point of writing for the situation 'frozen peas left in a room' that "*the room temperature enters the peas and turns them the same temperature as the room*". Moreover, in a later activity instead of a flow of energy she identified a flow of air; so for a 'cold lemonade in a warm room' she wrote that "*a lot of air is going inside*".

By both Rebecca and Naomi energy was seen as a localised substance-like quantity. Insulation was seen as a barrier to energy flow. About some insulated water pipes on a cold day (see activity 'Examples of insulation', E6, 'Energy', 8.2.2.4) Naomi wrote:

"For the one that has got the insulation the energy inside is trapped. Therefore only very little energy escapes."

That Naomi saw a temperature difference causing an energy flow there is no doubt. However, at the start she was not so sure whether absence of temperature differences entailed absence of energy flow. "*There is going to be some energy, a little energy going inside.... It is going in and then it is going to go out*", she told me. And of course strictly speaking she was right at the microscopic level; the state of equilibrium is a dynamic rather than a static state. In the following lesson however, her doubts seemed to have disappeared as she formulated a quite sophisticated explanation for why there is no energy transfer when we have coins at room temperature left on a table either uncovered or wrapped in a woollen bag (see activity 'Examples of insulation', E6, 'Energy', 8.2.2.4).

"When a coin is left in a room which has the same temperature no energy is going in or out. Because not one temperature is higher than the other. When it is insulated in a woollen bag and is still the same temperature as the room nothing happens because there is no concentrated energy higher than other form of energy."

The temperature of the system here was clearly considered relative to that of the surroundings at a high level of generalisation. Her argument, furthermore, was maintained even for the more difficult situation of a snowman wrapped in a coat on a freezing day. Rebecca's first reaction when she encountered this situation was that it was going to melt "*because it going to get hot*" just as "*if you put an ice cube on your hand and you cover it, it will start to melt*". Naomi, more correctly wrote:

"If it is cold and the day is cold and temperatures are the same, then no energy is being released or is entering. [...] Even if it is insulated,

if the temperature around the object is the same as the one inside the object then no energy is going in or out."

Finally, the ultimate question would be whether Naomi also saw temperature differences as driving changes of state. This was not an idea that was pursued in the Year 8 materials and thus there was only one example in Naomi's workbook. About some frozen food left on a table (see activity 'Examples of insulation', E6, 'Energy', 8.2.2.4), she wrote:

"[...] the concentrated energy from the room goes in the frozen food to melt the ice. It melts the ice because the energy is concentrated. More heat. [...]"

In this example she does not explicitly attribute any role to the temperature difference between the room and the frozen food. However, her explanation could be taken on the whole as satisfactory. Having said this, the project would eventually want to minimise explanations in which energy is thought of as causing changes to happen. The same kind of reasoning was used by Naomi to explain why a bubble of coloured water in an open-ended tube moves upwards when immersed in a beaker of hot water (see activity 'Making an engine', B7, 'Food and fuels', 8.2.3.2). The energy of the hot water was said to make it rise.

Stores of concentrated energy and energy flows

In the project's materials energy is also shown as flowing from stores of concentrated energy such as fuel-oxygen systems. How was the idea that energy can be stored in stretched chemical springs understood by the two girls? Unfortunately, I do not have copies of Rebecca's answers for the corresponding activities that took place near the end of the school year, and I only have Naomi's answers for the activity 'Ways of storing energy' (H4, 'Food and fuels', 8.2.3.3). In it she wrote about storing energy by electrolysis water:

"When water is electrolysed the energy inside splits the 2 hydrogen and 1 oxygen. The energy is splitting them and is in the middle, so the energy is stored. The particles are pulled apart. This is a driven action. This energy is hidden."

What is particularly interesting in the above quote is that energy was seen as being stored not in one of the two sorts of particles but in their system, "in the middle" as Naomi described it. The idea that "energy inside needs to be a lot to keep the hydrogen and oxygen apart" as Naomi explained it elsewhere in the same activity is not trivial, and at the same time is essential for understanding a large number of biological changes, such as photosynthesis or respiration.

Spontaneity

In the above excerpt Naomi also made clear that she understood that the storing of energy is not a spontaneous process but needs to be driven. Two months prior to this activity in the test at the end of the topic ‘Substances’ comparing ‘some wood burning’ and ‘a metal bracelet tarnishing’ Naomi had written that

“One thing which is different is that the metal bracelet can be made new, but the wood can’t.”

However, there is not enough evidence to assert that by the end of the year she had realised that for both changes the reverse processes do not ‘just happen’ and thus need to be driven by changes that ‘just happen’.

Use of abstract pictures

A major characteristic of the project’s materials is the use of abstract pictures. Both pupils did not seem to have any significant problems understanding them and using them successfully. Rebecca seemed to have a small difficulty at the start with the picture that represented a gas; she seemed to identify a gas not according to the arrangement of the particles, but when the particles in the picture had no shading. Similarly in the pictures she drew at the test she only barely observed the conventions for representation of the three states of matter, whereas Naomi was careful in using both different symbols to represent different substances and different arrangements (the ones introduced in the materials) to show the different states. Their transition from one kind of particle pictures in which different particles had different shadings to the other in which particles joined together to form new particles was also smooth. When in the activity ‘What happens when new substances are made?’ (G4, ‘Substances’, 8.2.1.7) they had to use them for the first time and to choose the one that shows what happens to copper when it is heated in air, there was considerable discussion among them about which picture is the right one. Of the two pictures they disagreed on, one shows a solid made out of a substance A and a gas - substance B - reacting and joining to form a solid AB, and the other shows the same thing except that in the ‘After’ picture the solid is of a substance C. Using the previous kind of conventions the second picture is the right one and Rebecca seemed to favour this answer, but with the new kind of conventions the first picture shows best what happens to copper. Naomi wrote that she found the choice tricky but opted for the first picture.

Identifying similarities and differences

There was only one activity in the Year 8 materials - ‘Matching changes’ later renamed ‘Everyday changes’ (F5, ‘Substances’, 8.2.1.6) - where the pupils had to

talk about similarities and differences between changes after matching them to abstract pictures. I have already cited Naomi identifying a difference between ‘some wood burning’ and ‘a metal bracelet tarnishing’; for the same changes she also identified one similarity:

“One thing in common is: it becomes a different substance and the colour of it changes.”

I take this similarity to be at a desirable level of generalisation. However, even unsupported by the abstract pictures both Naomi and Rebecca were very successful when reasoning about similar changes. In the test at the end of the topic ‘Substances’, pupils were asked to identify from a total of six changes the one most like water turning to ice in a freezer (which was labelled ‘it is easy to get it back - we can take the ice out of the freezer to get the water back’). Rebecca chose the change ‘stretching a rubber band’ because,

“The rubber band is stretched to make it longer, but you can get it into the same state as it was.”

Indeed, both changes are physical changes and are easy to reverse, but it is not obvious that pupils who had not been exposed to the particular teaching would have identified these similarities.

8.4.2 Isma and Sahnia

Isma and Sahnia were girls of average achievement. They seemed to be close friends and always sat together. Although English was not their native language they used it comfortably both orally and in their writing. They worked together with another two girls who were of the same ethnic origin but whose English was very poor; they helped them with the school work and often acted as interpreters. On the whole they were rather timid; however, though rather quiet, their contributions in the classroom discussions were usually very valuable. Their books were very neat and tidy and their writing was of a good standard.

Both of them worked well and hard with the project’s activities. Isma was in general more wordy in her explanations and descriptions, whereas Sahnia was more laconic with hers. Also, some of the project’s activities seemed to be missing from Sahnia’s book although, according to the observation records, she was present in the relevant lessons. They both participated eagerly in the interviews and seemed to enjoy them. They maintained a friendly sense of competition between themselves, which proved very fruitful in the interviews; they often complemented each other offering rich and sophisticated explanations for their choices.

Changes to matter

The distinction between a ‘substance’ and an ‘object’ and the identification of changes of substance proved difficult for them at the start, just as for Naomi and Rebecca. Similarly to them ‘ice’ and ‘water’ were thought to be different substances. Moreover, in the ‘Wearing out’ activity (F2, ‘Substances’, 8.2.1.2) used at the start of the topic ‘Substances’ Isma listed the situations ‘a rubber ball perishes’ and ‘rain erodes a limestone building’ under the heading ‘the object changes, but the substance stays the same’, and the situations ‘an aluminium can is crushed and ‘a plastic waterproof hat gets a hole’ under the heading ‘the substance changes to a different substance’. The criterion Sahnia seemed to use in the subsequent activities to decide whether a substance had changed was to look for changes in the colour of the substances. This criterion is one that is also implicitly suggested by the practical activities in their textbook. Colour change, however, cannot be the only criterion for identifying a chemical reaction. Thus, putting Alka Seltzer in water is a chemical change which is not accompanied by a change of colour; washing the dirt off your hands is a physical change despite being accompanied by a change of colour. The disadvantage of the convention which represents different substances by different shadings, is that it tends to reinforce this belief. Sahnia wrote the following explanation about why she matched the change ‘glue becoming hard’ to the picture that showed a liquid becoming a solid of the same substance (see activity ‘Matching changes’ - later renamed ‘Everyday changes’, F5, ‘Substances’, 8.2.1.6):

“I matched B [‘glue becoming hard’], because 3 [the abstract picture] shows that liquid goes hard but the colour doesn’t change. So the colour doesn’t change in B.”

Similarly to Naomi and Rebecca, Isma and Sahnia found it particularly difficult to differentiate the changes of ‘dissolving’ from the chemical changes between a solid and a liquid. The first attempt was made as part of the activity ‘Matching changes’ - later renamed ‘Everyday changes’ - (F5, ‘Substances’, 8.2.1.6), and as with Naomi and Rebecca, was not successful. More interesting, however, appears to me Isma’s attempt in the test at the end of the topic ‘Substances’ to match and explain the changes ‘dropping acid onto limestone to make a gas’ and ‘dissolving some instant coffee in water’; she chose the right pictures to match them to and wrote for each respectively:

“The acid is dropping onto the limestone and the acid melt the limestone and it mixture with the liquid and there’s left the liquid and bit gas, and it is a new substance.”

and

“The coffee which is the solid and water which is the liquid mix together and become liquid, but there is two things in the liquid and it is a new substance.”

I gather from the above two explanations that although Isma had not mastered or adopted the scientific uses of terms such as ‘mix’ or ‘melt’, and was still unsure about what constitutes a new substance, with the aid of the abstract pictures she described successfully and in her own words the nature of a solution. Unfortunately, Sahnia did not take the same test as she was absent that day, and thus I cannot speculate about her progress in this respect.

The distinction between ‘joining’ and ‘mixing’ and correspondingly between ‘splitting’ and ‘unmixing’ became somehow easier with the aid of the new particle pictures. The new difficulty with using these pictures was that one needed to name the reactants and products of the chemical reactions and it was not enough to talk about ‘a new substance’. So, for changes with which the pupils had some familiarity, like the reaction of hydrogen with oxygen (see activity ‘Joining, splitting, mixing and ‘un-mixing’ - some examples’, G6, ‘Substances’, 8.2.1.8), Isma would write:

“[...] the hydrogen and oxygen gases join together and they form water - clean water - and it is a new substance.”

naming easily the participants before and after the change. On the other hand for more complex changes, like the extraction of copper from copper sulphate solution by electrolysis, she failed to do this correctly, saying for example in her end-of-topic test:

“The copper and copper sulphate solution were joined together but then by using electrolysis it gets splitted.”

In the ‘burning’ changes, just like Naomi and Rebecca, originally Isma and Sahnia recognised a role for fire but not for oxygen. By the end of the topic, however, Isma would tell Sahnia about ‘heating iron’ that *“it [iron] turns black because of oxygen - it joins with oxygen”* and Sahnia would ponder over whether the oxygen just *“covers the iron”* or *“goes inside”*.

Temperature differences and energy flows

The ideas introduced in the ‘Energy’ topic were adopted rather easily by Isma. All the activities done in this topic are missing from Sahnia’s book, with the exception of one, which appears incomplete.

Isma did not make use of the term ‘concentrated energy’ in her work; however, she correctly identified the direction of the energy flows and took care to mention in most of the cases that the temperatures of the system and of its surroundings end up the same. Only once, in the second activity in the topic, did she slip into saying that

as a result of the energy flow the system and its surroundings would end up having the same energy.

It is difficult to say whether Isma saw temperature differences as driving energy flows. In most of her explanations she focused on the transfer of energy, which she saw, just like Naomi and Rebecca, as a localised quantity, and on the temperature changes incurred in the system and its surroundings - separately and in relation to each other. So, she described what happens to some ice cubes which are put in a glass of lemonade (see activity 'Energy transfers in the kitchen', E3, 'Energy', 8.2.2.2) as follows:

"The lemonade temperature was the same as the room but when it gave the energy to the ice cubes it became a bit cooler than the room. The ice cubes become a bit warm, but it doesn't become the same temperature as the room. At the end the lemonade and the ice cubes become the same temperature."

In the above quotation I find it interesting that she accounts for the temperatures of the participants not just in absolute terms (the ice cubes become a bit warm) but also in relative terms (the lemonade became a bit cooler than the room; the ice cubes don't become the same temperature as the room; the lemonade and the ice cubes become the same temperature). In implicitly acknowledging the importance of the temperature of an object relative to other things that are in contact with it, Isma could have been seeing temperature differences as driving energy flows.

From examples like the above, but also from other instances of her writing, some of which I will mention below, I conclude that Isma did see temperature differences as driving energy flows. In the activity 'Examples of insulation' (E6, 'Energy', 8.2.2.4) Isma was happy to reason that *"nothing is going to happen"* to a snowman on a freezing day (or to a snowman wrapped in a coat), because *"the snowman is already frozen and the day is freezing"*. In other words, the absence of a temperature difference results in the absence of a thermal change. Finally, in the following activity 'Getting hotter and colder' (E4, 'Energy', 8.2.2.4) she justified why the picture showing a test tube with water at 20°C in a beaker with water at 60°C comes before the picture that shows the water in the test tube and in the beaker at 50°C, using explicitly the idea in question:

"[...] the beaker's water is more hotter so it gave energy to the tube and the beaker water temperature becomes 50 C and the tube water becomes 50 C."

About the role of insulation, Isma saw it as being one of keeping heat from coming in. Similarly to Naomi and Rebecca, insulation was seen as reducing the amount of energy flow and not the rate of energy flow. In Isma's words:

“[...] the things which don't have insulation get more energy, and the things that have insulation get less energy.”

From the little evidence I have about Sahnia, I can say that for her the idea that energy flows only from hot to cold did not always appear straightforward. In considering a match for the change ‘water pipes on a cold day in winter’ she originally insisted that *“the pipes cannot give out energy because the cold day ...is stronger”* and that consequently energy should be going in. The notion of ‘coldness’ flowing is based on experiences we have with our body and is very resistant to change; Sahnia’s reaction is a mere instance of it. Also, Sahnia was more prone than Isma to reason that fur around a beaker of water will result in an increase in the water’s temperature, which is another popular misconception among children.

Stores of concentrated energy and energy flows

Both girls had reasonable and desirable accounts about the two ways that energy can be stored and released. Sahnia explained how energy is stored when water is electrolysed to give hydrogen and oxygen (see activity ‘Ways of storing energy’, H4, ‘Food and fuels’, 8.2.3.3):

“The energy is getting into the water to store itself by splitting the water. The particles are being stretched like a spring. This change needs to be driven.”

I find that she expressed the intended ideas in quite a successful way, making effective use of the analogue of the stretched spring. Again, unfortunately, the evidence is not enough to permit me to speculate on how deeply they understood these ideas, or on how easy they found it to use them. I can only say, from their explanations like the above about the ways of storing energy, exemplified in the case of water, that Isma and Sahnia had an understanding of the intended ideas and were able to use them to describe what is happening to water when it is heated or left to cool, when it is electrolysed or left to form from hydrogen and oxygen.

Use of abstract pictures

They seemed to cope very well with the abstract pictures. Isma’s own pictures in the test at the end of the topic ‘Substances’ show that she had understood the conventions and that she could reproduce them effectively to describe three unfamiliar changes.

Sahnia, as mentioned before, encountered some difficulty with the first kind of picture; she consistently read the change of shading of the particles to mean change of colour. So the reason she gave for deciding which picture best shows what

happens to copper when it is heated (see activity ‘Heating copper’, G3, ‘Substances’, 8.2.1.7) was:

“I chose C because the copper started of with 2 things and it ends with one thing which changes the colour completely.”

The reason would have been more desirable if she had spoken of change of substance instead of change of colour.

Identifying similarities and differences

The ‘joining’ of two substances was much more efficiently described with the aid of the new particles. Having matched the changes ‘rusting’, ‘heating copper’, ‘hydrogen and oxygen’ and ‘heating iron and sulphur’ under the picture of ‘joining’ (see activity ‘Joining, splitting, mixing and ‘un-mixing’ - some examples’, G6, ‘Substances’, 8.2.1.8) the two girls, in similar words, wrote:

“All of these ones were first two substances and after the change they join together and make a new substance, as the diagram shows.”

Four chemical changes so different in their particulars were described above by a single sentence which however, captures the essence of them. Enabling children to find apparently different situations similar by considering the abstract generalised features of the processes, is one of the major objectives of the project. A generalised account at this high level is most desirable in science if it is coupled with knowledge about the specifics. Here it was arrived at with the help of the abstract pictures.

8.4.3 Ravi and Ching Man

Ravi seemed to be a pupil of average and Ching Man of less than average attainment. In fact the latter was the lowest attaining pupil examined in the Year 8 pupil case studies. Both boys were very attentive in the classroom and worked hard. Ravi, though still not very active, participated more willingly in classroom discussions, and was more assertive, whereas Ching Man preferred to keep to himself. They usually worked in the same group; their collaboration however was not as strong as it was between the other two pairs. Moreover, Ravi left the school before the end of the school year - just before the end of the ‘Energy’ topic.

Ravi’s and Ching Man’s workbooks were well kept; most of the activities in them appear complete and the accounts of the experiments were always organised under the same set of headings. Small pieces of encyclopaedic knowledge about topics related to their lessons were also present. Ravi’s writing was of a good standard; he could express himself easily both orally and in writing. On the other hand Ching Man’s writing was often next to illegible and his command of written English was

often not as good; the combination of these two made it hard for me to read and understand what he wrote.

Both Ravi and Ching Man worked vigorously with the project's activities. Ravi's answers were much more extended and elaborate; Ching Man's answers show that he struggled with the ideas presented to him. My impression is that Ravi had the potential to do better than he did, if he were challenged more either by the teacher or his working group.

Changes to matter

The ideas introduced by the project materials in the topic 'Substances' proved challenging for Ravi, and hard for Ching Man. Just like the other four pupils, distinguishing the chemical from the physical changes was what they struggled with throughout the topic. Ravi throughout the topic used the term 'dissolving' to describe a solid turning into a liquid due to its interaction with another liquid. It is unclear what criterion he used to decide whether the 'dissolved' substance turned into a new substance - reacted with the liquid - or not. In the 'Matching changes' activity (later renamed 'Everyday changes', F5, 'Substances', 8.2.1.6), unlike the other four pupils, he matched the change 'putting Alka Seltzer in water' to the right picture but this decision was influenced by the fact that the picture showed gas being emitted after the reaction, which he said he knew was the case, and not by the fact that the picture showed the production of a new liquid substance, as he told me. On the other hand, the situation 'using rust remover on an old car' was matched to the picture of 'dissolving'. Moreover, similarly to the four girls before him, he thought that 'washing the dirt off your hands' was a chemical change:

"The dirt is dissolving in the water and the solid particle is turning it into a new substance."

Ching Man, having done the activity with Ravi, had the same matches as him, but with less elaborate explanations for them.

It is also not very clear whether Ravi saw changes of state as changes of substance or not. In the above activity the changes of state were matched to the right pictures, but in the test at the end of the topic he wrote that *"the butter is melting to make a new particle"*. However, it is only fair to say that he wrote this to explain why 'melting some butter' is most like 'some water turning to ice in a freezer' and added that *"it is easy to change that particle back to solid just like the ice"*. Physical changes are indeed more easily reversible than chemical changes; Ravi seemed to implicitly acknowledge this. Ching Man on the other hand for the same question chose the change 'heating copper in air to make copper oxide' showing that he did not hold as

firmly the distinction between physical and chemical changes. Furthermore in the same test he matched ‘ice melting’ to the picture of ‘dissolving’ and justified it:

“I chose this because when you melt ice it turns to two substances.”

It is difficult to say with ~~any~~ ^{certainty} what he meant, but his answer points rather to a misunderstanding of the change by him than to a misunderstanding of the abstract picture.

Let us now investigate what difference the introduction of the pictures of ‘joining’, ‘splitting’, ‘mixing’ and ‘un-mixing’ did to Ravi and Ching Man’s conceptions about chemical and physical change. Interestingly, when Ravi was asked to find out information about a number of changes, with a view to then reflecting on whether in them new substances were formed by particles joining or splitting, before the introduction of the corresponding abstract pictures, Ravi classified all changes as either joining or splitting and so did Ching Man. When he was asked, however, in the next activity to match almost the same changes to the abstract pictures in question he correctly distinguished the ‘mixing’ and ‘un-mixing’ changes as well as the ‘joining’ and ‘splitting’ ones. Moreover, the explanations he gave for the matches appear quite sophisticated, for example his justification for putting the ‘making of copper’ under the ‘splitting’ picture (see activity ‘Joining, splitting, mixing and ‘un-mixing’ - some examples’, G6, ‘Substances’, 8.2.1.8) was:

“To make copper from copper oxide you need to get rid of the oxygen. I chose this substance here because copper and oxide are together (top picture). Then you use a carbon rod and pass electricity to it. The copper then forms (bottom picture). The oxygen is separated.”

Despite being quite sophisticated, the above explanation still showed signs of the occasional misconception of terms and ideas. The process of ‘dissolving’ for example did not appear more demystified; to explain why he matched ‘dissolving sugar’ to the abstract picture of ‘mixing’ (see activity ‘Joining, splitting, mixing and ‘un-mixing’ - some examples’, G6, ‘Substances’, 8.2.1.8), Ravi wrote:

“I chose this here because it shows sugar and water separated on top picture but shows on the bottom picture there are only mixing. But some of the particles should have dissolved so they could make sugar solution.”

In other words Ravi still thought that changes at the microscopic level should somehow reflect the changes at the macroscopic level. The same kind of answers appear also in his test at the end of the topic ‘Substances’.

In Ching Man’s case the abstract pictures did not help him understand the difference between chemical and physical change; in the test he chose the wrong pictures to describe the three given changes, all of which he had experienced as practicals and

had discussed in the preceding lessons. Interestingly, however, his justifications for choosing these pictures once more show that he understood the conventions of the pictures, as his answers were consistent with what the pictures showed; they happened not to account for the specific changes. For example, he chose the picture of ‘splitting’ as best showing what happens to ‘purifying rock salt’ because

“The rock and salt are join together and they fall apart.”

and the picture of ‘un-mixing’ as best showing what happens to ‘extracting copper from copper sulphate solution’ because

“The copper and the copper sulphate is mix and when you use electrolysis they go apart.”

How was ‘burning’ perceived by the two boys? Ravi always took care to mention that you need fire for burning, and that fire needs oxygen; he further saw this oxygen as “*getting into*” the solid and forming a new substance. His belief that in heating something one needs oxygen, which then reacts with the substance that is heated to give a new substance, was very strong. When he drew a picture to show blue copper sulphate crystals being heated to produce water vapour and a white solid, he drew a solid and a gas for the ‘Before’ picture, and then the solid becoming gas and a new solid substance being left in its place, as if the solid had partly evaporated and had partly reacted with the air/oxygen to give a new substance. Ching Man in his first attempt to account for ‘burning’, in the activity ‘Heating copper’ (G3, ‘Substances’, 8.2.1.7), chose the picture that showed that air simply was deposited on top^{of} and around copper without reacting with it; in a later activity though he correctly explained that “*copper joins to the air*”.

Temperature differences and energy flows

The next question is how Ravi and Ching Man managed with the ideas of the ‘Energy’ topic. Here the difficulties faced have already been documented in the performance of the four girls. From the few activities I have from Ravi, I noticed that he did not make use of the term or the idea of ‘concentrated energy’. On the whole, he saw energy as being ‘given’ or ‘taken’ and acknowledged that this transfer results in the system changing its temperature; he talked of the system and its surroundings as having the same temperatures and equal energies at equilibrium; and finally he thought of insulation as reducing the amount of energy flow and not its rate. Ching Man also did not make use of the idea of ‘concentrated energy’, he, however, succeeded in identifying the directions of the energy flows in the thermal changes in the activities, as well as the temperature differences that cause them. The abstract pictures used in the activities seemed to help him a lot to form reasonable explanations about the thermal changes; moreover, they seemed to structure his

explanations. For example, in the activity ‘Energy transfers in the kitchen’ (E3, ‘Energy’, 8.2.2.2) where the pictures show a ‘Before’ and an ‘After’ instance for each change, Ching Man also accounted for both instances in his explanations. On the other hand, in the ‘Examples of insulation’ activity (E6, ‘Energy’, 8.2.2.4), where the pictures show only the ‘Before’ instances, he limited his accounts to identifying the temperature differences and the energy flows when they existed; he thus did not identify the temperature changes incurred by the energy flows, nor did he mention that the temperatures of the system and its surroundings end up the same at equilibrium. In this he was different from the rest of the pupils studied. Furthermore, in the activity ‘Getting hotter and colder’ (E4, ‘Energy’, 8.2.2.4), where no abstract pictures are used, his explanations of why one instance proceeds another were very unsatisfactory.

Stores of concentrated energy and energy flows - Spontaneity

Finally, Ching Man struggled to understand how energy can be stored in fuels and food and how two changes can be coupled. There is no evidence that he understood the symbolism of the arrows of spontaneity. Whereas he attempted some explanations for what happens to water when it is heated, is left to cool, is electrolysed and is formed when hydrogen and oxygen react, in a later activity ‘Fuels and food’ (H5, ‘Food and fuels’, 8.2.3.4) he matched the changes ‘a bath of hot water cools down’ and ‘a person uses up food running a race’ to the same abstract picture showing energy escaping through cooling. It is worth noticing, however, that in the activity just mentioned he matched the cooling and warming changes correctly and also the only chemical change that could be thought as familiar to him, ‘wood burning’.

Use of abstract pictures - Identifying similarities and differences

I have already made some remarks about the use of the abstract pictures. Ravi seemed on the whole to have no problems interpreting their conventions and replicating them to make his own pictures. He did not use them so much as a way to generalise about similarities and differences between different changes, but they helped him formulate more abstract and sophisticated explanations. Ching Man also did not seem to have any difficulties reading what the pictures showed, he rather faced difficulties with the ideas they represented. I have already discussed how the pictures structured his explanations. In the pictures he drew in the test at the end of the topic ‘Substances’ he maintained the convention that different colours or symbols for particles meant different substances, but failed to represent correctly the states of the different substances and their interactions. He also found difficulties in identifying similarities between two changes. ‘A car rusting’ was said to be most like

‘some toast being made from bread’ just because “*there is something changing in both of them*”.

8.4.4 Summary

The above accounts follow the progress of three pairs of Year 8 pupils in the course of some five months. This progress can be summarised in the following points:

- Not surprisingly, all the above pupils found it difficult to identify changes of substance correctly and thus to distinguish the chemical from the physical changes. However, the use of the abstract pictures encouraged them to identify relevant features and make explicit to themselves the difficulties involved in classifying the changes.
- By the end of the topic on ‘Energy’ all six children could identify more or less correctly the energy flow present in a thermal change and showed some appreciation that this was due to a temperature difference between the system under investigation and its surroundings. The main difficulty the pupils had here was distinguishing between the intensive quantity of temperature and the extensive quantity of energy; the abstract pictures did not seem to help them in that respect.
- The ideas of a ‘chemical spring’ and of coupled changes proved to be the most challenging to the pupils. Nevertheless, they were not totally inaccessible; most of the pupils managed to make some sensible use of them in their explanations.
- Consistently with the above finding the pictures which seemed to present more difficulties to the pupils were the ‘chemical spring’ pictures. With this exception, the pupils on the whole did not seem to have any major problems understanding the abstract pictures and were able to use them successfully to support their explanations.

CHAPTER 9

Year 8 Interviews with Pupils

9.1 Introduction

This chapter is the equivalent of chapter 7, for Year 8; it contains the analysis of the Year 8 interviews with pupils. Similarly to the Year 7 interviews, these interviews were analysed from a variety of perspectives, focusing on specific tasks and on pupils' progress in them across time.

The last section of the chapter (section 9.5) comprises the conclusions concerning Year 8 pupils' progress in relation to the specific objectives of the intervention, and drawing on the findings reported in chapters 8 and 9.

9.2 'Grouping' task: Comparison of all Year 8 first (A) and last (D) interviews

This section is looking at the kinds of similarities (and differences) the Year 8 pupils identified and at whether these changed as a result of the intervention. For this purpose it compares their performance in the 'grouping' task in the first and last sets of interviews (for more details about the rationale of this analysis see subsection 5.7.4.1).

9.2.1 Description of 'grouping' task in first (A) and last (D) interviews

As already explained in chapter 5, the A set of interviews was carried out with both the Year 7 and the Year 8 pupils before any teaching using the project's materials took place. The situations used in these first (A) interviews covered a variety of changes and were:

- scent or after-shave evaporating from the skin
- *ice forming on a pond*
- a cold drink left out in the sun
- *acid rain eroding a stone statue*
- hot lava from a volcano turns solid
- making soup out of powder soup and water
- fruit drying in the sun
- *a plant growing*
- a car windscreen being shattered

- *wood burning*
- *digesting food*
- *a hot bath cools down*

On the other hand, the situations used in the last (D) set of interviews were more related to the topic of ‘Food and Fuels’, the teaching of which had immediately preceded the interviews. These situations were:

- *a plant growing*
- *running and using up food*
- *ice forming on a pond*
- *charging a car battery*
- *wood burning*
- *acid rain eroding a stone statue*
- *pulling a catapult to get ready to fire a stone*
- *a hot bath cools down*

The situations that were common to both sets of interviews appear in italics. Two tables for each of these two sets of interviews can be found in the Appendix (appendices 9.1, 9.2, 9.3, 9.4). One table shows with the aid of arrows the matches each group of pupils made. The second table is a matrix of all possible combinations of the situations showing which of them were chosen by each of the groups. It should be noted that in the D interviews only four groups of pupils were interviewed compared with five groups in the A interviews, due to the high turnover of pupils in the school (see section 5.3).

9.2.2 Pupils identifying similarities

9.2.2.1 Kinds of groupings suggested in the first and last interviews

According to the criteria discussed in subsection 5.7.4.2, the kinds of groupings the pupils suggested in the ‘grouping’ task of the first (A) and last (D) interviews were coded as ‘arbitrary’, ‘script’, ‘opposites’, ‘similarities’ and ‘no reason’/‘unclear’. The relative frequencies of these categories in the two sets of the Year 8 interviews were then compared (see Table 9.1).

This comparison between the first (A) and last (D) interviews shows that in the A interview 75% of the total identified groupings were coded as ‘similarities’ and ‘opposites’, whereas in the D interview this was the case for 94% of them. Also, 15% of the suggested matches were coded as ‘arbitrary’ and 10% as ‘no reason’ or ‘unclear’ in the first interview, compared with 3% respectively in the last interview. This increase in the frequency of the more appropriate kinds of groupings in the last

interview was also observed in the equivalent analysis of the Year 7 interviews (subsection 7.2.2.1). Moreover, it seems to confirm the assertion made there that by the end of the intervention the pupils were more able to focus on the *given* changes and perform reasonable comparisons of them, than at the start of it.

YEAR 8 INTERVIEWS 'GROUPING' TASK	'Similarities' 'Opposites'	Script	Arbitrary	No reason Unclear
A Interviews (n=37)	75%	0%	15%	10%
D Interviews (n=34)	94%	0%	3%	3%

Table 9.1 *Kinds of groupings suggested in the Year 8 A and D interviews*

9.2.2.2 'Similarities' and 'opposites' in the first and last interviews

The comparison of the A interviews with the D interviews, with regard to the kinds of 'similarities' and 'opposites' that the Year 8 pupils identified, found that the percentage of similarities (and differences) which referred to the changes, as opposed to only the objects (and their properties), involved in the given situations increased from 78% in the first interview to 97% in the last (see Table 9.2).

YEAR 8 INTERVIEWS 'GROUPING' TASK	'SIMILARITIES' AND 'OPPOSITES'		'SIMILARITIES' AND 'OPPOSITES'	
	Between Objects and Properties	Between Changes	Actual	Potential
A Interviews (n=57)	22%	78%	66%	34%
D Interviews (n=32)	3%	97%	84%	16%

Table 9.2 *Kinds of 'similarities' and 'opposites' in the Year 8 A and D interviews*

Moreover, the frequency of 'actual' similarities and differences, as opposed to 'potential' ones, rose from 66% in the first interview to 84% in the last interview (Table 9.2). These results agree with what was found to be the case for Year 7 (see subsection 7.2.2.2), that is that at the end of the intervention the pupils were able to focus more successfully on what *is happening* in the situations presented to them and to compare them on this basis. However, as with the results for Year 7, this positive shift was not also detected in the 'quality' of the identified similarities; the percentage of these which referred to the processes (physical, chemical or biological)

involved in the changes, rather than simply to the macroscopic observable events associated with them, seemed to drop slightly (from 56% to 47%) from the first to the last interviews.

9.2.3 Pupils' spontaneous accounts of changes

There were no surprises in the comparative analysis of pupils' spontaneous accounts of the changes in the two sets of interviews. Similarly to what was found before, in the last (D) interview the pupils reasoned much more about what they saw as *happening* in the situations, than about the *entities* present in them (85% compared to 15%). This was also the case in the first (A) interviews, but to a much lesser degree (65% compared to 35%). However, once more, accounts seen as more desirable through the project's spectacles did not appear more often in the D interviews.

In both sets of interviews the pupils gave elaborate accounts for close to 60% of the changes. In the first interview the terms used in these accounts were characterisations of temperatures, of physical states or names of processes (e.g. melting or mixing), whereas interestingly in the last interview, the term mostly used (in 57% of the elaborations) was 'energy'. Having said this however, in only nine out of the 21 instances where it was used, the term 'energy' was employed in a desirable way from the project's point of view. An example of a less desirable account, given for the situation 'running and using up food', is shown below:

"It's using up all the energy that it's got."

In it energy is portrayed as a substance-like quantity that can be used up and disappear. On the contrary, the following explanation, given for the situation 'ice forming on a pond', was considered as more appropriate since it attempts to account for the change of state of water into ice using the idea of energy flow:

"Because the hot water is giving out all the energy and cools down, and the ice is forming on the pond."

9.2.4 Comparison of pupils' spontaneous accounts of changes common to first and last interviews

Another way used to examine comparatively the two sets of interviews was to look at how the pupils talked about the changes that were common to them (see subsection 5.7.4.4). These, also indicated in the previous section, were:

- ice forming on a pond
- acid rain eroding a stone statue
- a plant growing

- wood burning
- a hot bath cools down

From the tables in appendices 9.1-9.2 and 9.3-9.4 one can see to which other change(s) each of the above changes was linked. So, for example, in the A interview ‘a plant growing’ was found similar to ‘wood burning’ by two groups of pupils, and to ‘digesting food’ and ‘food drying in the sun’ by one group. On the other hand, in the D interview three groups matched this change with ‘ice forming on a pond’; one group out of these three also matched it with ‘charging a car battery’ and ‘wood burning’, and a fourth group chose it as a match for ‘running and using up food’. ‘A plant growing’ is a situation for which one would not expect to see much change in Year 8 pupils’ reasoning. The majority choice of ‘ice forming on a pond’ as a match could be an indication that there was some change in their reasoning, even if only minimal. First, because this choice was available in the first interview, but was not made by any of the groups then, and second, because this choice is one the project would find desirable since in both changes substances are bunching together. However, only a close study of the matches and the justifications given for them could provide evidence of a shift in pupils’ reasoning.

In the following subsections I will trace the matches by two groups of pupils, whose composition remained unchanged across both sets of interviews.

9.2.4.1 Finding a match for ‘ice forming on a pond’

In both the first and last interview the situation ‘ice forming on a pond’ was matched to ‘a hot bath cools down’ by the first group of pupils. It is interesting however, how the reasons for this match changed between the two interviews. In the first interview, the comparisons of the two changes concerned solely the participants of the changes and their properties. As the following extract shows the pupils identified that both situations involved water, and examined whether there is any relationship between its temperature and physical state in the two situations.

P: *“Both are waters and one of them is ice and the other hot - not really. They got the same sort of temperature.*

P: *Except that one is ice, that’s hot water.*

P: *Yeah, it cools down - it might not.*

P: *It can’t be the same. This is solid, that one is liquid.”*

The above comparisons are certainly considered desirable from the project’s point of view, but somehow they do not go far enough, because they stay at the level of the object and do not consider what is *happening* in the changes. Moreover, the pupils

themselves appeared to recognise that there was something more to be said about the two situations, but could not arrive at identifying it.

“Water, water - not just because of that. I don’t know, I just think those two go together.”

Five months later now, in the last interview, the ability of the same pupils to reason about similarities between changes had clearly developed. The reverse match (of ‘a hot bath cools down’ with ‘ice forming on a pond’) was now justified as follows:

“Because that’s ice forming on a pond - first it was water and then it’s ice forming -, and that’s a hot bath cools down. So, in other words, that’s cooling, but so is that. But that’s cool already, it’s just getting even cooler, and that’s cooling down.”

This time the children, without relinquishing their attention to the difference between the two temperatures of the water in the two situations, were able to reason more generally that in both situations the change of temperature observed is one of cooling down.

The second group’s progress was also quite impressive. At the start of the first interview, the pupils found the situation ‘a hot bath cools down’ to be an unsuitable match for ‘ice forming on a pond’; instead, they chose ‘acid rain eroding a stone statue’ as its match. The reasoning behind this choice went as follows:

“I think it might be the acid one because it says ice, and it’s got rock stone over here, but it’s got to be water on it. It’s hard like ice - stones [she is referring to the stone statue].”

Later on, however, in the same interview when thinking about a match for ‘a hot bath cools down’, prompted perhaps by the name of this latter situation, the pupils seemed to be reconsidering and getting closer to a more desirable comparison:

P1: *“It could go with the ice because the ice is cold and the bath water gets cold.”*

P2: *Yes, the ice gets cold.”*

In the last interview, any hesitation about this match appeared to be minimal; the pupils assertively concluded that ‘ice forming on a pond’ goes with ‘a hot bath cools down’ because

“... the hot water is giving out all the energy and cools down, and the ice is forming on a pond...- the pond was normal and it gave out all the energy it had and became ice.”

This explanation goes in my opinion further than the previous one in that it attempts to account for the similar process observed in terms of an energy flow (see also section 9.2.3).

9.2.4.2 Finding a match for ‘acid rain eroding a stone statue’

There was no explicit mention of the change ‘acid rain eroding a stone statue’ in the Year 8’s teaching materials; however, the project’s materials addressed a number of similar chemical changes, and one would hope that they would have influenced the way the Year 8 pupils reasoned in the last interview about this change. This influence however was not detected in either of the groups’ explanations about the change, even though the matches the pupils suggested for it in the last interview were on the whole more desirable than those offered in the first interview.

One of the groups, for example, matched ‘acid rain eroding a stone statue’ with ‘scent or after-shave evaporating from the skin’ in the first interview, and with ‘wood burning’ and ‘a hot bath cools down’ in the last. The similarity in the first case was ‘arbitrary’, whereas in the second the pupils reasoned that the objects involved in the suggested pairs were “*getting smaller*” as a result of the change (the statue as a result of erosion, the water in the hot bath as a result of evaporation and the wood as a result of burning).

9.2.4.3 Finding a match for ‘a plant growing’

At the beginning of this analysis I mentioned that not much progress was expected in the way the pupils reasoned about this situation as a result of the intervention. However, the choice of match (‘ice forming on a pond’) that the majority of the groups had made for it in the last interview, and which was not present in the first interview, had intrigued me and made me wonder if their reasoning of the situation had changed in some way. Close examination of the justifications given by the two groups for the matches they suggested for ‘a plant growing’, seem to indicate that this change was minimal. For example the group who had matched ‘a plant growing’ with ‘ice forming on a pond’, said they did so on the basis of macroscopic observations that in both situations something is becoming “*bigger*”, and not because they saw that in both of them matter is bunching together. It should be noted that this situation had not appeared in the project’s teaching materials used with Year 8; a somewhat similar situation (‘a plant makes starch by photosynthesis’) had appeared only once as part of the topic ‘Food and Fuels’ towards the end of the intervention, with the focus being on the energy change and not on the relevant matter change.

9.2.4.4 Finding a match for ‘wood burning’

The project’s materials dealt explicitly with the teaching of burning, so one would expect this to be reflected in how the pupils’ talked about the change ‘wood

burning’, in the last interview. The data suggest that although the pupils’ reasoning about it moved forwards in some respects, at the end of the intervention it was still some distance from where the designers of the materials would wish it to be.

In the first interview both groups identified superficial similarities at the level of the object (e.g. ‘wood burning’ is similar to ‘hot lava from a volcano turns solid’ because in both cases there is ash), or by treating the changes as ‘events’ (e.g. ‘wood burning’ is similar to ‘fruit drying in the sun’ because they are both ‘like dying’). In the last interview the pupils explained their matches in terms of what is happening to the energy involved. This I consider as a positive step, although I recognise that the ideas the pupils expressed about energy were commonsensical, and particularly in one of the cases, were not what a science educator would want Year 8 pupils to have. One group said that ‘wood burning’ is similar with ‘running and using up food’ because they are both ‘using up all the energy they have got’, and the other group found ‘wood burning’ similar with ‘a hot bath cools down’, because they both ‘give out energy for people to use’. This last identification of energy as flowing out from the two systems may have been prompted by the project’s teaching.

9.2.4.5 Finding a match for ‘a hot bath cools down’

As one would expect, this situation seemed more straightforward to the pupils from the first interview; both groups correctly identified the relevant physical process in it. In addition, they made substantial progress in the kinds of similarities they identified between the two interviews. Examples of this progress have already been mentioned in the discussion of the two groups’ justifications for pairing ‘ice forming on a pond’ with ‘a hot bath cools down’ (see subsection 9.2.4.1). In one of those examples, we saw one group of pupils shifting the focus of their comparisons from the common ‘object’ (‘water’) of the two situations, and its properties (‘temperature’), to their common physical process (‘cooling down’), from the first to the last interview. We also saw the pupils of the second group arriving at a quite sophisticated justification for the match in the last interview, in terms of energy. It is true that both groups also made less appropriate matches for ‘a hot bath cools down’ in the last interview (see above how one group matched it with ‘wood burning’); the way they justified them however was overall considerably more desirable at the end of the intervention, than at its start.

9.2.5 Summary of findings

The results of this analysis seem consistent throughout, as well as with those found in the equivalent analysis for Year 7. The statistical evidence in the first part of the

analysis was exemplified in the context of the five situations examined in the second part. The pupils could perform the task more successfully after the intervention; they were more able to reason about the *given* changes and, unlike the first interview, they rarely resorted in forcing ‘arbitrary’ similarities between them. Moreover, a positive shift was observed in the kinds of features the pupils focused on in their comparisons: from the entities present in the changes to the processes they saw as happening.

By the end of the intervention the pupils were still far from spontaneously identifying similarities based solely on what is happening to energy and matter in a change. Similar results were also noted in Year 7 (see section 7.2.5). On the other hand, in the last interview we found a number of occasions, usually in connection with the ‘easier’ thermal changes (e.g. ‘a hot bath cools down’), where they attempted explanations in energy terms, and suggested similarities on this basis. I perceive this result as related to the preceding teaching about energy.

9.3 ‘Matching’ and ‘comparing’ tasks: Comparison across Year 8 Group 1 interviews

This section contains the analysis of the ‘matching’ (second) and ‘comparing’ (third) tasks across the four interviews for one group (which I will call Group 1) of Year 8 pupils. The equivalent analyses for the other two groups can be found in appendices 9.5 and 9.6.

9.3.1 Chemical change: Matter ‘joining’ and ‘splitting’

The phrase ‘a substance changes’ was used only in the first interview, the phrase ‘it makes a new substance’ was used in the first and third interviews and the abstract pictures of ‘joining’, ‘splitting’ and ‘re-arranging’ appeared in the second interview.

9.3.1.1 ‘A substance changes’ - ‘It makes a new substance’

In the first interview the pupils chose the expression ‘a substance changes’ and/or the expression ‘it makes a new substance’ as true for seven out of the eight situations which were presented to them. The first one was employed more freely to describe material and temperature changes alike, whereas the second one was chosen only for the situations which either involved a material change (either physical or chemical), identified usually in concrete terms at the level of the object, or in which a ‘new’ object was thought of as being made. For example in ‘wood burning’ wood was said to change to ashes and in ‘a plant growing’ new fruits or leaves were said to appear. The same observations were made in the first interview of the Year 7 pupils.

In the third set of interviews the phrase ‘it makes a new substance’ was meant (by design) to appear as a prompt in the ‘comparing’ task, in relation to three pairs of situations. However, this group did not do this task and therefore it cannot be said whether they progressed any further in their use of it.

9.3.1.2 ‘Joining’ - ‘Splitting’ - ‘Re-arranging’

The pictures of ‘joining’ and ‘splitting’ were introduced to the Year 8 pupils to describe chemical changes during the topic ‘Substances’ which preceded the second interview. The picture of ‘re-arranging’ on the other hand was met by the pupils for the first time in the second interview. It used the same conventions as the other two pictures, only this time to show a reaction which combined somehow the joining and splitting of particles - a displacement reaction.

The pupils had the chance of using these three pictures in only one out of the four interviews. As a result there is no evidence about whether their use improved with time.

‘Joining’

The pupils had difficulties in seeing ‘joining’ as ‘joining substances’. Three changes were matched by one or more pupils to the abstract picture of ‘joining’: ‘a snowman melting’, ‘a car rusting’ and ‘a baby’s bones growing’. For ‘a snowman melting’, the picture of ‘joining’ was an inappropriate match, but it was suggested by only one pupil, who promptly discarded it when another pupil challenged her explanation that “*the snow and the sun join up*”. Rusting was a change they had previously discussed in their lessons, and as a result ‘a car rusting’ was successfully seen as ‘joining’ - to begin with by one of the pupils, and eventually by three out of the four. However, their identification of the reactants and of the product of the reaction was not so desirable, not only because it was not always correct (e.g., the rust was seen as joining on to the car by one pupil), but also because it was at the level of object, rather than at that of substance (e.g., the air and the car were said to join and turn into rust). As for the situation ‘a baby’s bones growing’ the reactants were not known, which was expected, but it was explicitly recognised that the product of a ‘joining’ process is a new substance.

‘Splitting’

The picture of ‘splitting’ was initially chosen as a match for five situations, and was finally kept for two. The intended match was with ‘extracting copper by electrolysis of copper sulphate solution’, a change the pupils had seen as part of an investigation. All the pupils agreed with this match from the beginning, but as before

they found difficulty in naming the substances which participated in the reaction. The pupils' use of the term 'splitting' most of the time was not as they had been taught. By using it to describe what is happening in 'cleaning a paintbrush in water' and in 'purifying water' it was clear that some children considered it as a synonym of 'separating' or 'un-mixing', whereas the teaching materials had intended it to be used strictly for chemical changes. Moreover, they seemed to favour, as was the case with 'joining', a macroscopic use of the term, where objects and not particles are seen as splitting. As an example of this, it is worth mentioning an intense discussion, which took place between two pupils as to whether 'a snowman melting' is a 'splitting' change. The pupil who won the argument maintained firmly that

"...when it's melted, the water goes away, and the cold air or whatever the other substance is, goes away too, so it's being splitted up."

She thought that, because

"...ice is not just water. If it was just water, you could've drunk it, but it contains something."

She may not have managed to fully convince the other three girls with this argument, they however accepted her explanation, and kept the match.

'Re-arranging'

Finally, there was no evidence that the pupils understood the abstract picture of 're-arranging'. They chose it in relation to four changes and kept it for two: 'a baby's bones growing' and 'metal foil being crumpled up'. Its match to this latter change was advocated by only one pupil; she used the term in its everyday meaning to talk about a change of shape. On the other hand, the pupil who decided to match it to 'a baby's bones growing' treated it as a 'joining' process of more than two substances:

"A bone contains a lot of substances, and when it's being made bigger, it think it has, maybe one or two more substances added to it."

9.3.2 No change: Matter 'staying the same'

The use of the phrase 'substances stay the same' by the pupils in the first interview confirms what was said before about what they considered to be a change of substance. More precisely, they explicitly denied that substances stay the same in 'a cold drink left out in the sun' and in 'a hot bath cools down', as the first was seen to evaporate and the second to cool down. The progress in this respect was obvious in the second and third interviews. The pupils were happy to agree to match the picture of 'no change' to the situation 'metal foil being crumpled up' in the second interview, and to the situations 'an electric iron cools down after being switched off',

‘warming your hands by the radiator’ and ‘your body staying warm on a cold day’ in the third. In the case of ‘metal foil being crumpled up’ they also explicitly argued that there is “*no new substance*” made: “*...It’s just getting smaller. There’s no change in it*”.

9.3.3 Physical change: Matter ‘mixing’ and ‘un-mixing’

The phrase ‘something is mixing’, in the first interview, was mostly applied generously and with its everyday sense to describe six out of the eight changes, including chemical changes. As was also noted in the use of the terms ‘joining’ and ‘splitting’ the pupils identified concrete objects (e.g., pond, air, wood, soup, acid rain or even sun and fire), rather than substances, as mixing. This is partly justified however, since in many of the cases the names of the substances involved were not known.

The same observation was made for the use of the term ‘mixing’ in the second interview. There, all the pupils chose the picture showing ‘mixing’ as a match for the situations ‘cleaning a paint brush in water’ and ‘putting Alka Seltzer in water’. The second change had repeatedly appeared in the project’s classroom activities. In the pupil case studies (section 8.4) I discuss extensively the problems its match presented to the pupils, who more generally had considerable difficulties in differentiating between processes of ‘dissolving’ and ‘reacting’. It is in the context of this discussion that I found it interesting that, although the match selected for ‘putting Alka Seltzer in water’ was not appropriate, in her explanation a pupil accounted for the process of ‘mixing’ in rather desirable terms:

“They’re mixing, they are not becoming a new substance, they’re just mixing. They’re next to each other.”

I, moreover, find it reasonable to suggest that the production of an explanation like this is aided by the existence of the relevant abstract picture.

The abstract picture ‘unmixing’ was chosen appropriately for the situation ‘purifying water’. However, the reasoning for why the process was one of ‘unmixing’ and not of ‘splitting’ was not based on any of the criteria that differentiate a physical from a chemical change. For example one pupil used what she perceived as the physical distance of the products of the change as a criterion:

“It’s separated, it’s not splitting, because splitting means you split it in the same container. But it’s not going to be in the same container - one’s going to the filter paper and one is going here. [...] And unmixing does not mean in the same container, but this one does.”

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 was also clear to me that as a result of the intervention the need for this differentiation was something that they had become conscious of, and sometimes partially managed.

9.3.4 Temperature differences and energy flows

The metaphoric expressions ‘energy spreads out’ and ‘energy becomes concentrated’ were introduced in the topic ‘Energy’, and were associated with the abstract pictures showing respectively a temperature difference disappearing and being created. In the topic ‘Food and Fuels’, which followed, (and in its corresponding interview (D)), the same pictures appeared labelled as ‘energy escapes I’ and ‘energy is stored I’ respectively. In this way the teaching materials prompted explicitly and implicitly the pupils to compare and contrast them with the ‘new’ pair of pictures introduced in that topic, labelled as ‘energy escapes II’ and ‘energy is stored II’. These latter showed energy flowing from and to systems moving down or up a chemical potential gradient.

9.3.4.1 ‘Energy spreads out’ - ‘Energy becomes concentrated (in something)’

‘Energy spreads out’

As can be expected the use of the expression ‘energy spreads out’ in the first interview 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 ‘energy spreads out’ with its literal meaning; the emphasis was more on the changing object, rather than on the flow of energy. This is very explicit in the following quotation about ‘wood burning’:

“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 ‘energy spreads out’ when a plant grows because:

“The sun spreads all over the thing.”

Four months later, in the third interview, the pupils still associated the spreading out of energy with the spreading out of matter, to the point of choosing in some cases the ‘spreading out’ picture, which showed particles first together and then spread out, to reason about energy spreading out. Having said this, there was also a clear shift of

emphasis in their explanations compared with the second interview. This time, there was a number of references to energy flows and to temperature changes with the systems ending up at the same temperature as their surroundings. Also, on the whole, concentrated energy was seen to reside in hot things, but cold things were seen to have no energy, rather than ‘diluted’ energy.

The picture ‘energy spreads out’ was chosen by one or more pupils in relation to six out of the eight situations; it was finally kept as a match for five of them, namely for ‘an electric iron cools down after being switched off’, for ‘water vapour forms clouds and it rains’, for a candle burning labelled ‘melting wax’, for ‘smoke filling the air over a city’ and for ‘an explosion’; for all five there were acceptable arguments for the matches, even when the latter were not the intended ones. As I mentioned before energy was often seen as 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.”

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 I consider as desirable and as largely imposed by the symbolism of the abstract pictures, was clearly felt by some pupils. We see the following pupil struggling to contain this necessity in her account of ‘water vapour forms cloud and it rains’:

“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.”

Concentrated energy was equated to concentrated stuff. This conception often led to less desirable explanations as in the case of ‘melting wax’ where the spreading out of energy was related to the wax’s change of state from solid to liquid and not to a temperature change.

‘Energy becomes concentrated’

The use of the picture ‘energy becomes concentrated’ evolved on similar lines in the third interview. The picture was matched originally to four changes, but was finally kept as a match only of ‘warming your hands by the radiator’ - an intended match - and of ‘your body making extra fat’. 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 contrived to manage 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 ‘energy becomes concentrated’ picture with a ‘spreading out’ 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 doesn’t exactly like bunch together, but it spreads around sort of thing, but it makes your hand get hotter.”

9.3.4.2 ‘Energy escapes I’ - ‘Energy is stored I’

Finally in the fourth interview, a month after the third one, the pupils applied the same pictures (but now with labels ‘energy escapes I’ and ‘energy is stored I’) as they were meant to, that is only in relation to thermal 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 ‘energy spreads out’ and ‘energy becomes concentrated’ distracted the pupils into reasoning about concentration changes, and thus the change of these labels to ‘energy escapes I’ and ‘energy is stored I’ 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 set.

Another difference in the children’s 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 ‘ice forming on a pond’ 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 situation ‘a hot bath cools down’ was also matched correctly to the picture ‘energy escapes I’. In fact, all situations matched to this picture were also matched to the picture ‘it just happens by itself’, again as desired.

The picture ‘energy is stored I’ was chosen for the situations ‘a plant growing’, ‘charging a car battery’ and ‘wood burning’, but was only kept for ‘wood burning’. Wood was seen as becoming warmer, and fire to be the agent of this. However, no energy flow was explicitly identified. In a later reference to ‘wood burning’, in the ‘comparing’ task, the pupils explicitly talked about energy flowing in and out of the system, but did not elaborate further.

Summing up, it is necessary to note that despite the improvement observed in the children's use of the pictures of 'energy transfer' their notion of what energy is did not seem to get clearer or more desirable. The following quotations suggested this to me:

(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."

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: 'running and using up food' and 'wood burning' were said to be similar because *"they both use up energy"*.

9.3.5 Stores of concentrated energy and energy flows

'Energy escapes II' - 'Energy is stored II'

The pictures 'energy escapes II' and 'energy is stored II' 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. Right from the start of the interview the pupils asked me to explain to them again what these pictures showed. I did that several times in the course of the interview. Also in order to minimise the level of disagreement among the group, for each situation I asked them first to decide all together on whether energy was going out or in the given system, and only then to choose (individually) which of the abstract pictures best represented it. In this way, I wanted to help them focus on two of the energy pictures at a time for each situation, and thus to make their choice easier.

Despite all these difficulties, both pictures were matched appropriately; the 'energy escapes II' picture to the change 'running and using up food', and the 'energy is stored II' picture to the changes 'a plant growing', 'charging a car battery' and 'pulling a catapult to get ready to fire a stone'. However, from the explanations the pupils gave for their matches, it became clear that they understood little of what the abstract pictures represented. A number of pupils 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 ‘running and using up food’ to the picture of ‘energy escapes II’, but explained:

“I think like say you put food in your mouth, so like your stomach sort of expands sort of thing, and then you’re jogging you use it all up and it like doesn’t 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.

Consistently with the above observation, the change all pupils matched correctly (with the picture ‘energy is stored II’) on their first attempt was ‘pulling a catapult to fire a stone’.

On the positive side, a choice of the picture ‘energy escapes II’ was almost always combined with the choice of the picture ‘it just happens by itself’, and equivalently the choice of the picture ‘energy is stored II’ was combined with the choice of the picture ‘it needs something to make it happen’. Given that, as noted earlier, ‘energy escapes I’ and ‘energy is stored I’ were similarly appropriately combined, I take this as a possible indication that the pupils had started associating an out-flow of energy with a spontaneous process, and respectively an in-flow of energy with a non-spontaneous one.

9.3.6 Steady-state systems:

‘No energy change’ - ‘Energy stays concentrated’

The pictures ‘no energy change’ and ‘energy stays concentrated’ appeared in the third interview for the first time for the pupils. One showed a system at thermal equilibrium with its surroundings, and the other a system at a constant temperature difference with its surroundings maintained by a continuous flow of energy in and out of the system. The ‘no energy change’ picture was also used in the fourth interview.

The picture ‘no energy change’ was originally chosen for three situations by one or more pupils. It was an appropriate match for only one of them: ‘smoke filling the air over a city’, but was instead kept as a match for ‘your body staying warm on a cold day’. The justification given by the two pupils, who made this match (the other two pupils matched it to the picture ‘energy stays concentrated’), was that no energy was coming out / spreading out and no temperature was changing. However inadequate

and incomplete this argument, it identified the intended elements of energy flow and temperature change.

Another pupil understood the expression ‘no energy change’ to mean no overall energy change. So in ‘melting wax’ he argued that at first energy goes out as it melts, but then it starts to cool down and thus *“it becomes concentrated like it was before”*.

In the fourth interview the same picture was chosen as a match for the situation ‘acid rain eroding a stone statue’, but no explanation was given for it.

The picture ‘energy stays concentrated’ was picked as a match for four situations, but was not finally kept for any. What was noted before for the uses of the pictures ‘energy spreads out’ and ‘energy becomes concentrated’ was also observed with the use of this picture. A hot candle was said to have concentrated energy and retain it, but also smoke was said to stay concentrated (it was unclear whether the pupil referred to the temperature of the smoke or to the smoke itself). Only for the change ‘your body making extra fat’ was there a mention of some sort of an in- and out-flow of energy; energy / fat was said to come in through eating and to get used up through exercise. Finally, the pupils did not have time to discuss the suitability of this picture to describe the change ‘your body staying warm on a cold day’, as the interview was terminated unexpectedly.

9.3.7 Spontaneous and non-spontaneous change

The four expressions ‘it (just) happens by itself’, ‘someone makes it happen’, ‘it needs something to make it happen’, ‘it is easy to reverse the change’ concern the issue of reversibility and more specifically the first three are for describing spontaneous and non-spontaneous changes respectively. A brief discussion about the origin of these expressions and the meaning intended for them can be found in section 7.3.7 of the thesis.

9.3.7.1 Phrases: ‘It happens by itself’ - ‘Someone makes it happen’

In their first interview the Year 8 pupils interpreted the phrases ‘it happens by itself’ and ‘someone makes it happen’ to mean the absence (or presence, respectively) of an agent in a change; this agent was often seen to be a human action. As noted earlier (see subsection 7.3.7.1), this was also seen with the Year 7 pupils. 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 ‘by itself’. 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 ‘it happens by itself’ was used there as a prompt. As a consequence the changes ‘putting Alka Seltzer in water’ and ‘cleaning a paintbrush in water’ 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.

9.3.7.2 Pictures: ‘It just happens by itself’ - ‘It needs something to make it happen’

The corresponding pictures ‘it just happens by itself’ and ‘it needs something to make it happen’ were used only in the fourth interview, after having being introduced in the preceding topic of ‘Food and fuels’. This time the pupils’ usage of the ideas involved was rather more sophisticated and desirable. The picture ‘it just happens by itself’ was chosen as a match for six situations but was finally kept for three. For all three, but also for two of the ones which were dropped, it was an appropriate match. These three included the physical changes ‘ice forming on a pond’ and ‘a hot bath cools down’; unlike the first interview, no pupil seemed to hesitate this time about their matching. Moreover, the explanation of why ‘acid rain eroding a stone statue’ ‘just happens by itself’ 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. There’s not electrical or anything forcing the acid rain to, you know, touch the stone statue. It’s 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 (of external agents driving a non-spontaneous change) 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 ‘just happen by themselves’, were present in some other explanations, even if not always using the most desirable wording. For example, a

pupil justified matching the situation ‘running and using up food’ to the picture ‘it just happens by itself’ because *“it don’t need no help taking energy out”* and another one agreed because *“every single thing that you do [...] you’re using up energy, so the energy is just coming out naturally”*. The possible pitfall in interpreting the expression ‘it just happens by itself’ as ‘it happens naturally’ has already been identified in the corresponding analysis of the Year 7 interviews (section 7.3.7). In the present analysis it is further exemplified by the fact that a pupil justified ‘a plant growing’ as happening by itself on the basis that *“it happens naturally”*. Returning to the previous point, ‘wood burning’ was also said to ‘happen by itself’ because *“[...] the wood is already done - you won’t need the energy to go in in the first place”*. Both changes however, ‘running and using up food’ and ‘wood burning’, originally intended to be thought of as spontaneous, were eventually left matched to the picture ‘it needs something to make it happen’. For the situation ‘running and using up food’ the decision was taken after an extended and heated discussion. The arguments against it being accepted as ‘happening by itself’ were that energy has to come in before it can be released - *“you need the food for that person to run”*- and that an activity is needed to trigger the release of energy – *“you aren’t 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 ‘wood burning’ 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 ‘wood burning’ or not. Defining the system as well as what constitutes the ‘Before’ and ‘After’ 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 doesn’t 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, it’s burning*

OK, it's burning by itself, you don't 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 wouldn't, the fire wouldn't 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 it's already burning you don't need anything else to make it burn more. It's burning and it's burning and it's just happening by itself and the energy is going out and the thing is getting cold."

P: "Miss, this thing isn't very clear, so it's very confusing about this thing, wood burning. I mean they might as well put it out as 'wood is burning', or 'how does wood burn', because I'm getting confused now."

The picture 'it needs something to make it happen' 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 - 'a plant growing', 'charging a car battery' and 'pulling a catapult to get ready to fire a stone' - appropriately. In none of these cases was it explicitly acknowledged that another spontaneous change needs to happen to drive these changes.

9.3.7.3 'It is easy to reverse the change'

Similar observations were made for the application of the phrase 'it is easy to reverse the change' to the ones written for the Year 7 interviews. The focus seemed to be more on identifying the 'reverse change' 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 'reverse process'.

From the first interview, the pupils did not seem (on the whole) to have difficulties correctly recognising the reverse processes of physical changes. In the case of the change 'cleaning a paintbrush in water' (which appeared in the second interview) they also described the mechanism - filtering - and acknowledged that *"it's going to be hard, unless you filter it a thousand times"*. For more complicated changes, like 'extracting copper by electrolysis of copper sulphate solution' or 'charging a car battery' 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, suggesting the repetition of the change instead of the reversal of it - *"say it [the car battery] runs out, you can charge it again"*. This 'repetition of the change' strategy was only seen in the last interview, but was used there for all the changes discussed (even for the 'easier' one 'a hot bath cools down'). This rather suggests an incorrect reading of the phrase 'it is easy to reverse the change', rather than an incorrect use of it.

9.3.8 Summary of findings

The above accounts show the progress achieved by one group of four Year 8 pupils as a result of the intervention. In the majority of the cases we saw the pupils arriving at appropriate matches for the situations they were given. However, it was often clear from their explanations that they struggled with the ideas involved. They clearly found difficult for example distinguishing between physical and chemical changes. Also they found hard to use intelligently the abstract pictures of ‘energy escapes II’ and ‘energy is stored II’. On the other hand, the pupils’ use of the pictures of energy flow due to temperature differences seemed to improve significantly. Finally, the ideas of spontaneity and reversibility provoked some very interesting and extended discussions in the last interview, which rather suggests that the pupils had started engaging with and reflecting on them, by the end of the intervention.

These and other traces of progress (or their absence) were looked for in the interviews of another two groups of pupils. The analyses of these interviews can be seen in appendices 9.5 and 9.6.

Finally, the analyses of all three groups are brought together in the discussion of the conclusions concerning the use of the project’s approach and materials with the Year 8 pupils (section 9.5).

9.4 Situations common to more than one interview: Comparison of explanations

This section summarises the results of the analysis of the accounts that the Year 8 pupils gave aided by the use of abstract pictures and phrases (i.e. as part of the interview tasks ‘matching’ and ‘comparing’), for the situations which were common to more than one interview.

These situations were:

- a hot bath cools down
- ice forming on a pond
- acid rain eroding a stone statue
- wood burning
- a plant growing

An example of this analysis for one group of pupils can be found in appendix 9.7.

The results of this analysis confirm the findings reported in the previous analyses. The most impressive progress in pupils’ reasoning was noticed in relation to the

situations in which energy was seen as flowing as a result of a temperature difference. In the case of ‘ice forming on a pond’ some pupils even attempted to link this flow of energy with the change of state observed. The accounts offered for ‘acid rain eroding a stone statue’ and ‘a plant growing’ changed the least over time; quite a few pupils saw the erosion of the statue as a dissolving process, and not unexpectedly, no pupil seemed to know how energy is stored in a plant. Finally, the situation ‘wood burning’ produced some interesting discussions amongst pupils in the last interview, about the direction of the energy flow and the spontaneity of the change.

9.5 Conclusions concerning the use of the project’s approach and curriculum materials with Year 8 pupils (R.Q. A2.3)

This section draws on all the previous pieces of analysis of the use of the project’s materials with and by the Year 8 pupils, and discusses whether the pupils showed any progress with respect to the objectives that the project had set for them.

9.5.1 Physical versus chemical change

- **Did the pupils differentiate between changes where the particles are ‘joining’ or ‘splitting’ and changes where the particles are ‘mixing’ or ‘un-mixing’?**

Before answering this question, I will address three other more general questions which I feel that are closely related to it and perhaps logically precede it. These are:

- Did the pupils attempt to distinguish between physical and chemical change?
- Did they manage it successfully?
- Did they reason about physical and chemical change in particle terms?

To the first question the answer is yes. By the end of the intervention, and largely through the help of the abstract pictures, the pupils became aware that there are some processes which result in a change of substance, and there are others that do not. Temperature changes (e.g. situations like ‘an electric iron cools down after being switched off’) were not seen any more as substance changes, and in most cases changes of state (e.g., ‘ice forming on a pond’) were discerned as physical changes. This awareness was very much the goal (and the result) of using the first kind of abstract pictures, which represent a change of substance as a change of shading.

However, the pupils still found it difficult to differentiate between the notions of ‘substance’ and ‘object’. This issue had not been explicitly tackled by the teacher in

the classroom - the relevant project activity ('Wearing out', see subsection 8.2.1.2) had been done by the pupils without any guidance from the teacher, or any follow-up discussion about it afterwards. Moreover, many pupils lacked the necessary knowledge to be able to identify the substances participating in a given change - the activity that the teacher had planned in order to help the pupils familiarise themselves with some science facts about a number of changes, had not been done by most pupils (see 'Other lessons' in subsection 8.2.1.7). It is reasonable to assume that these factors contributed to the fact that a good number of pupils slipped between talking about a change of 'substance' to talking about a change of 'object' almost indiscriminately.

The lack of knowledge about the specifics of some changes also meant that the pupils had to rely exclusively on phenomenological observations for determining whether a change is physical or chemical. Not surprisingly, many pupils reasoned that a substance changes, because (or when) the colour of the object alters in the course of the change. It is probable that the choice of the abstract pictures' designers to represent the change of substance as a change of shading in the depicted particles re-inforced this misconception. As one would expect in this case, what the pupils found particularly difficult was differentiating between the physical process of dissolving and the chemical reaction of a liquid with a solid.

The answer to the second question is that, although the pupils did attempt to differentiate between physical and chemical changes, these attempts were on the whole not very successful. More particularly, the evidence suggests that the criteria the pupils based their decisions on were most often neither consistent nor desirable. Having said this, it is also true that for changes explored in the classroom, some as part of the project's teaching materials, the accounts the pupils gave were noticeably more extended and sophisticated, than for the rest of the changes.

Concerning now whether the pupils reasoned in particle terms about the changes, the data suggest that only few of them did. I have already mentioned some of the reasons which I think contributed to this persistence of macroscopic accounts. In addition, the project's stance on the representation of chemical change was not very clear from the start of the intervention. Only half way through the teaching of the topic 'Substances' did the authors introduce pictures which could promote explanations of chemical change in particle terms. The first kind of particle pictures used in the activities, showing particles changing substance, did not appear to do so. It is true that the authors tried their best to make the transition from the old kind of pictures to the new as smooth as possible, by providing a rationale for it and a relevant activity to be used in the classroom. However, some of the consequences of this sudden

change were hard to avert. For one, there was no time to optimise the design of the two kinds of pictures so as to reflect the rationale of the transition, and to assure continuity and coherence. In the final version of the materials, this has been rectified. Also, and perhaps most importantly, there was no time to acquaint the teacher with the new pictures, the rationale behind them, and the goals of their use. As a result, I think she did not give the necessary emphasis to this new kind of pictures, and did not explain to the pupils how they differed from the old. The importance of thinking and accounting for the changes in particle terms was never explained or pointed out.

Coming now to the original question, the results of the analysis suggest that only few pupils managed to differentiate between changes where the particles are ‘joining’ or ‘splitting’ and changes where the particles are ‘mixing’ or ‘un-mixing’. The corresponding terms were often used indiscriminately (e.g. ‘splitting’ to mean ‘un-mixing’), or/and in a macroscopic and commonsensical way (e.g. ‘joining’ of ‘objects’ instead of ‘substances’). On the other hand, with the aid of the abstract pictures what seemed to become clearer in pupils’ minds was that the product(s) of ‘joining’ and ‘splitting’ is/are new substance(s).

In considering this last result, apart from the reasons already mentioned, there is one more factor that should be taken into account. In an ideal situation, in which the project’s materials were incorporated in the Key Stage 3 and 4 science curriculum, the pupils of Year 8 would have previously learned (in their Year 7 lessons) that the physical changes of ‘mixing’ and ‘un-mixing’ are processes where substances are ‘spreading out’ and ‘bunching together’ respectively. Talking about these changes in particle terms in Year 8, and then contrasting them with the chemical changes of ‘joining’ and ‘splitting’ would have built on and extended this knowledge. The Year 8 pupils of this research did not have this opportunity.

9.5.2 Temperature differences and energy flows

- **Did the pupils look for temperature differences and identify energy flows due to these temperature differences?**

The data seem to me very definite on this point; in their accounts of thermal changes, the pupils often identified the relevant temperature differences, as well as the energy flows due to these differences. This was not the case at the start of the intervention and seemed to be greatly aided by the use of the abstract pictures. Prompted by them the pupils identified explicitly both the temperatures of the system and its surroundings, often one in relation to the other, and noticed that these tend to equalise as a result of the change. Moreover, they saw these differences as triggering energy flows, and identified their directions.

However, not all explanations derived in this process were unproblematic, or equally desirable. The notion for example of ‘concentrated energy’ presented some difficulties for the pupils. They made very little use of the actual term; from their explanations it was often clear that they equated ‘concentration of energy’ with ‘amount of energy’. In other words, something hot was said to have ‘a lot’ of energy, instead of ‘a high concentration’ of energy, and respectively something cold was said to have ‘no’ or ‘little’ energy. It should be noted that, for systems of constant volume, a decrease in concentration of energy is equivalent to a decrease in amount. Also, the pupils’ everyday experiences of energy changes were of changes in amount not concentration - they felt energy flowing to their hands from warmer objects, and from their hands to colder objects. The notion of ‘change in concentration’ was therefore more abstract for them, though inseparable (in most of their experiences) from the equivalent notion of ‘change in amount’. Further undesirable consequences of this way of reasoning were that the pupils associated insulation with reductions in the amount of energy flow rather than the rate, and felt that objects at thermal equilibrium have equal amounts of energy.

Related to this is the issue of talking about energy as ‘substance-like’. The pupils treated energy as a localised ‘substance-like’ quantity, and whereas there may not be any strong reason for why this is wrong, it seemed to lead them to argue wrongly that it is also used up in producing a change. This misconception has been reported by a significant number of research studies, and especially as it was present at the start of the intervention could not have been *caused* by it. However, there is evidence that the project’s materials may have re-inforced an identification of energy with material substance. After all, the project’s authors, in the booklet ‘Introducing a new approach’ (Boohan and Ogborn, 1996a) clearly state that the materials talk about energy as ‘substance-like’, and expressions such as ‘energy spreads out’ and ‘energy becomes concentrated’ are manifestations of this.

It is my belief that such expressions may have re-inforced the ‘substance-like’ conceptions of the pupils, with some unwelcome consequences. At its most extreme, this ‘substantiation’ of energy caused a number of pupils in the interview, which followed the teaching of the topic, to confuse changes in concentration of energy with changes in concentration of matter. For example, they reasoned that energy was spreading out, only because matter was seen as spreading out.

Further evidence that the precise wording associated with the project’s abstract pictures may have affected the pupils’ way of reasoning about energy, is the observed change of emphasis in pupils’ explanations of thermal phenomena in the last interview. In this the project’s expressions for the same pictures changed from

‘energy spreads out’ to ‘energy escapes’ and from ‘energy becomes concentrated’ to ‘energy is stored’. Correspondingly, pupils focused more in their explanations on the energy flow between the system and its surroundings, and less on the temperature differences between them.

9.5.3 Stores of concentrated energy and energy flows

- **Did the pupils identify energy as flowing from stores of concentrated energy such as fuel-oxygen systems?**

My impression is that there *was* some progress in correctly identifying energy flows during chemical as well as physical changes. However, the teaching about fuel-oxygen systems was not enough to get very far. The relevant ideas of stores of concentrated energy and energy flows, which are widely considered as hard to understand, were taught in the space of only two lessons right at the end of the intervention (and of the school year), with the corresponding interview closely following. Moreover, these ideas in the project’s approach were introduced with the aid of a very original set of abstract pictures; the time the pupils had to familiarize with them and with their use was limited and thus their full potential impact on pupils’ explanations cannot be assessed. Finally, as one of the project’s authors (Richard Boohan) put it in his interview:

“Ideally one would need some time for pupils to sort of digest the work on temperature differences and energy flows, and then to have a pause - and maybe use these pictures now and again -, and then to move on as a separate piece of work on to the burning fuels. Because there isn’t, as it stands, enough contrast between the two. I think, it’s quite difficult to differentiate between the pictures and the meaning of what they are representing.”

As a result of these factors the research data was interpreted as showing how the pupils started to interact with these new ideas and materials, rather than as suggesting absolute outcomes for this interaction.

Overall, the children performed better in the project’s classroom activities, than in the interview tasks, and in the latter they gave more extended and desirable accounts in connection with the changes they had met in their lessons. This result is consistent with the assertion that the children had very little time to digest and/or reflect on the new ideas before they were asked to apply them in the more open-ended context of the interview. In it, their use of the ideas varied a lot, from very superficial to quite sophisticated. Burning was certainly understood as energy flowing out in fuel-oxygen reactions, but not well understood as coming from the forming of lower energy bonds than before. However, the teaching of this, as already said, was very limited.

The pupils similarly struggled with the use of the corresponding abstract pictures, showing a ‘chemical spring’ being released (or extended) with a consequent outwards (or inwards respectively) energy flow. In few cases, these pictures seemed to prompt very desirable accounts, in which, for example, energy was seen as being stored in the system (*“in the middle”*) of fuel and oxygen. However, in many occasions they were interpreted very literally and seemed to give rise to very superficial explanations. My overall impression, was that in the interviews the majority of pupils matched a change to a ‘chemical spring’ picture either when they did not think that the change was caused by a temperature difference, or when they thought that the action of the ‘spring’ was suitably analogous to what happened to the system in the examined change. No pupil, for example seemed to have any doubt that ‘pulling a catapult to fire a stone’ should be matched to a ‘chemical spring’ picture.

To conclude, what I think that the data showed us is that even though the pupils did not acquire much stable knowledge about stores of concentrated energy and energy flows, they engaged with these ideas, and managed to make use of them in their explanations.

9.5.4 Spontaneity and reversibility

- **Did the pupils consider that some changes ‘just happen’, while some do not, and that for a non-spontaneous change to happen there has to be a spontaneous one to drive it?**

As above, the ideas of spontaneity and of coupled changes appeared in the Year 8 teaching materials only towards the end of the intervention. As a result the pupils’ reasoning in these aspects progressed only minimally.

In some cases the pupils showed progress with the idea that some changes ‘just happen’. We saw for example that in the later interviews some pupils insisted that wood does ‘just burn’ once set burning, and that this is what matters, not whether a match had to be used in the first place. Moreover, almost all pupils showed signs that, as intended, they had started associating an out-flow of energy with a spontaneous process, and respectively an in-flow of energy with a non-spontaneous process.

However, the general notion of a spontaneous process does not seem to have been reached. Concerning in particular the idea of coupled changes, not once in the interviews did the pupils explicitly acknowledge that a non-spontaneous change needs to be driven by a spontaneous one. Again, the teaching of this was very limited.

As in the case of stores of concentrated energy and energy flows, what the data show here is that despite the fact that the pupils swayed in their understanding of the required ideas, they *could sometimes* use them in their explanations. In my view, this suggests that these ideas are usable and have the potential to be built upon with the help of the teacher.

CHAPTER 10

Teachers' Reactions to the Innovation

10.1 Introduction

One question of obvious importance is how teachers responded to the approach. An evaluation of a teaching approach would not be complete if it did not take into consideration the reactions of the people who are called upon to realise it in the classroom. In this thesis I am more interested in the possible learning outcomes of the approach, that is my main focus is on the pupils and their responses to the materials. However, these cannot but be informed by what the teachers think of the materials both in terms of the ideas they raise and their accessibility to pupils and teachers, and in terms of their ability to be incorporated in existing schemes of work. Moreover, it would not be wise to come up with assertions about how pupils cope with the materials without drawing on the experience of the professionals in the field.

In chapter 6 and 8 respectively I drew the profiles of the two teachers whose classes I observed, focusing mainly on how they dealt with the project's ideas and materials. In this chapter I look at how a larger sample of teachers reacted to the materials, after their first encounter with them.

More particularly, the first part of this chapter presents 42 science teachers' responses to a questionnaire about the project administered to them at the end of a one-day INSET session about the approach. The second part of the chapter discusses these responses and contrasts them with those given in hour-long interviews by the five science teachers of the school in which the innovation was tried out.

10.2 Presentation of data from questionnaire

The questionnaire contained fifteen statements about the project and the teachers were asked to indicate whether they strongly agreed, agreed, disagreed, or strongly disagreed with each. Nine of these were phrased in such a way that agreeing with them indicates approval of some aspect of the project (see also section 5.6.4). An example is: "It helps teachers to find simple ways of talking with pupils about energy and physical and chemical changes." Agreement with the remaining six questions indicates disagreement with, or disapproval of some aspect of the project. An example is: "Pictures are very abstract and have too many conventions. Pupils won't be able to make sense of them, even less use them."

Table 10.1 lists the statements used in the questionnaire organised thematically (see section 5.7.8 for more details and appendix 5.15 for the actual statement order) and presents for each statement the percentage of the teachers giving each of the four possible responses. The 'positive' statements are indicated by an asterisk.

Percentage of responses to the questionnaire statements				
Statements:	strongly agree	agree	strongly disagree	disagree
<i>The approach: the science behind it</i>				
1. It's certainly a different approach to teaching certain things, but I don't see what new ideas it introduces.	5%	12%	71%	12%
*2. The ideas are fundamental, and can help link together many parts of science, up to GCSE and beyond.	17%	83%	0%	0%
3. The ideas behind it are too general; what pupils need is a lot of interesting particular things to think about.	0%	27%	67%	5%
<i>Children interacting with the materials</i>				
*4. It helps keep the children active and busy, discussing and thinking.	9%	86%	5%	0%
*5. The activities are accessible to low ability pupils, and can help ones with language difficulties.	0%	52%	37%	10%
*6. The activities offer a challenge to higher ability pupils to think hard.	48%	50%	2%	0%
*7. It introduces the particle nature of matter in a way accessible to Year 8 and Year 9 pupils.	10%	67%	22%	0%
8. Pictures are very abstract and have too many conventions. Pupils won't be able to make sense of them, even less use them.	7%	59%	34%	0%
9. A special vocabulary to be learned which is not even scientific and is different from textbooks.	10%	45%	37%	7%
<i>Relating to practical experiences</i>				
*10. It is easy to see how some of the activities could follow practical work, building on it.	26%	69%	2%	2%
11. I don't really see the point of all the work comparing pictures and talking about them. Some practical experiences would be better.	3%	29%	55%	13%
<i>Teachers interacting with the materials</i>				
*12. It helps teachers to find simple ways of talking with pupils about energy and physical and chemical changes.	19%	74%	5%	2%
*13. It gets teachers thinking again about ideas they may not have felt very sure about, and helps them sort these ideas out a bit better.	19%	74%	7%	0%
<i>Incorporating the materials into the curriculum</i>				
*14. It can be used easily alongside existing schemes.	12%	65%	22%	0%
15. I don't see how I can find good places for the activities in the existing schemes of work.	0%	19%	60%	21%

Table 10.1 Percentage of teachers' responses to the questionnaire statements

The percentage of teachers giving each response to each statement is indicated graphically in figure 10.1 below in a descending order for the *strongly agree* response.

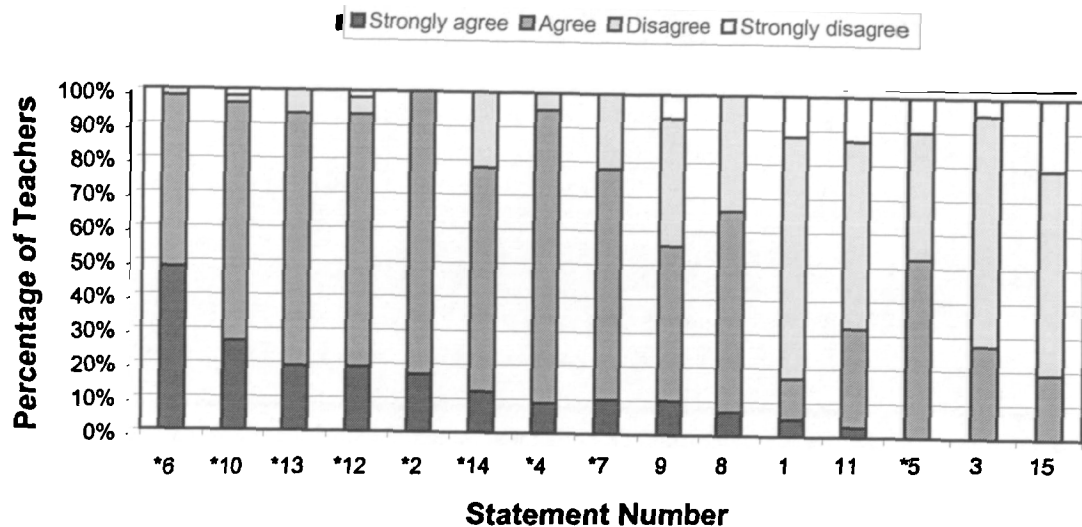


Figure 10.1 Summary of responses to the statements

The better to represent these data for analysis, two procedures were followed:

1. For each statement the responses were initially divided into two groups: the percentage agreeing with it (i.e. who answered with either *strongly agree* or *agree* in the questionnaire); and the percentage disagreeing with it (i.e. who answered with either *disagree* or *strongly disagree* in the questionnaire).
2. Since agreeing with some of the statements and disagreeing with other both imply agreement with the project's aims/materials, the agree/disagree groupings were re-represented for each statement as the percentage of teachers who gave positive responses towards some aspect of the project (i.e. agreeing with the asterisked statements and disagreeing with the others) and those who gave negative answers (i.e. disagreeing with the asterisked statements and agreeing with the others).

This re-representation was then used to produce the graphs in figures 10.2-10.6. It is hoped that they will give a more immediately understandable picture of the extent to which, for each statement, the teachers gave answers indicating feelings that were either positive or negative towards aspects of the project.

In the following discussion, the statement each comment refers to is indicated, e.g. S1 refers to statement 1.

As figure 10.2 shows, all the teachers agreed that the approach deals with fundamental scientific ideas (S2), though some doubted whether they were really new ideas (S1) and almost a third of them found the ideas too general (S3). Overall, teachers were very positive about this aspect of the new approach.

The approach: the science behind it

1. It's certainly a different approach to teaching certain things, but I don't see what new ideas it introduces.
- *2. The ideas are fundamental, and can help link together many parts of science, up to GCSE and beyond.
3. The ideas behind it are too general; what pupils need is a lot of interesting particular things to think about.

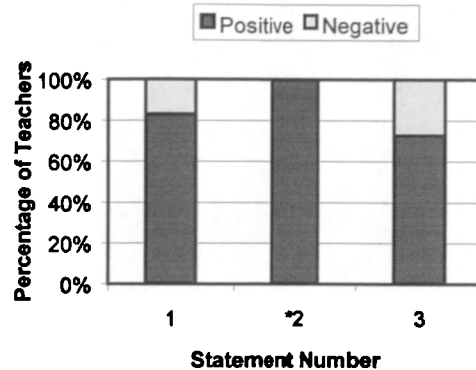
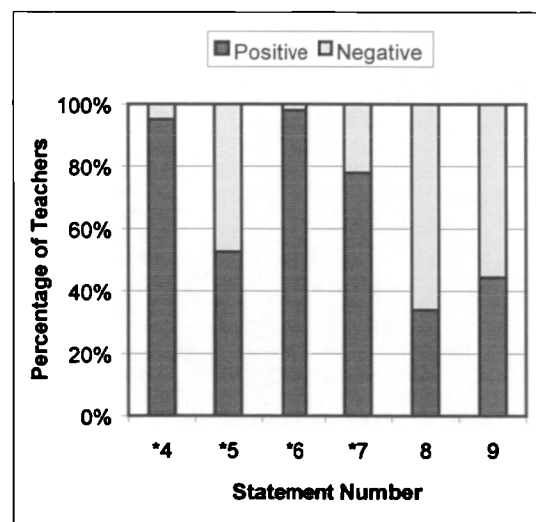
***Figure 10.2 Teachers' views about the new approach***

Figure 10.3 shows that the great majority of the teachers thought that the materials would keep the pupils positively active and busy (S4), would offer a challenge to higher ability pupils to think hard (S6), and introduced the particle nature of matter in an accessible way (S7). However, about half of them felt that the activities might not work with low ability pupils, or those with language difficulties (S5), and worried that a special and non-scientific vocabulary needed to be learned (S9). Moreover, about two thirds of teachers feared that the pictures would prove too abstract for the pupils to make sense of them (S8).

Children interacting with the materials

- *4. It helps keep the children active and busy, discussing and thinking.
- *5. The activities are accessible to low ability pupils, and can help ones with language difficulties.
- *6. The activities offer a challenge to higher ability pupils, to think hard.
- *7. It introduces the particle nature of matter in a way accessible to Year 8 and Year 9 pupils.
8. Pictures are very abstract and have too many conventions. Pupils won't be able to make sense of them, even less use them.
9. A special vocabulary to be learned which is not even scientific and is different from textbooks.

***Figure 10.3 Teachers' views about the use of the materials with children***

As figure 10.4 demonstrates, nearly all the teachers agreed that it is easy to see how some of the activities could help build on practical work (S10). However, a minority

were not very clear as to what the point of the work comparing pictures and talking about them was and thought that some practical activities instead would be better (S11).

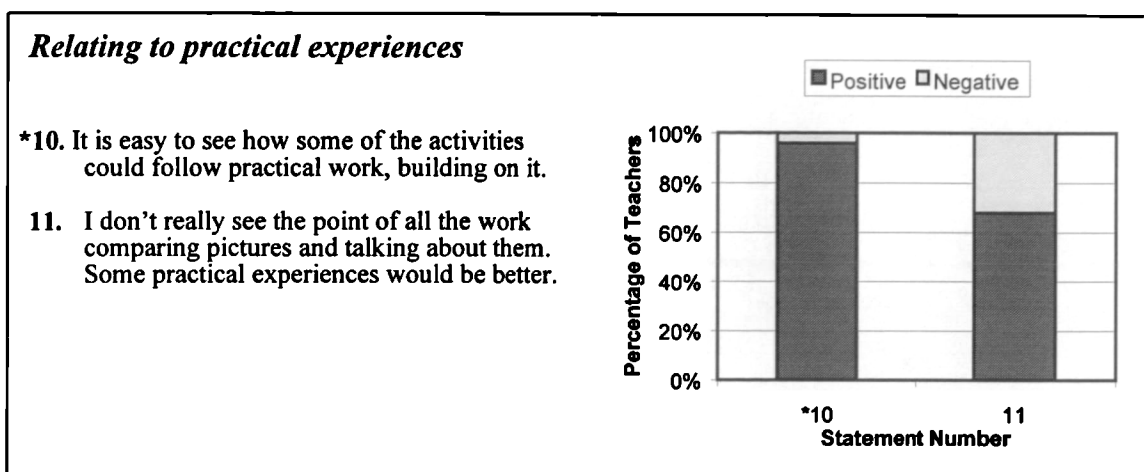


Figure 10.4 Teachers' views about the relationship of the materials to practical work

Figure 10.5 shows an even more favourable set of responses with virtually all the teachers feeling that the project's materials would help them both to think again and improve their own understanding of energy and physical and chemical change (S13) and find simple ways of talking about it with pupils (S12).

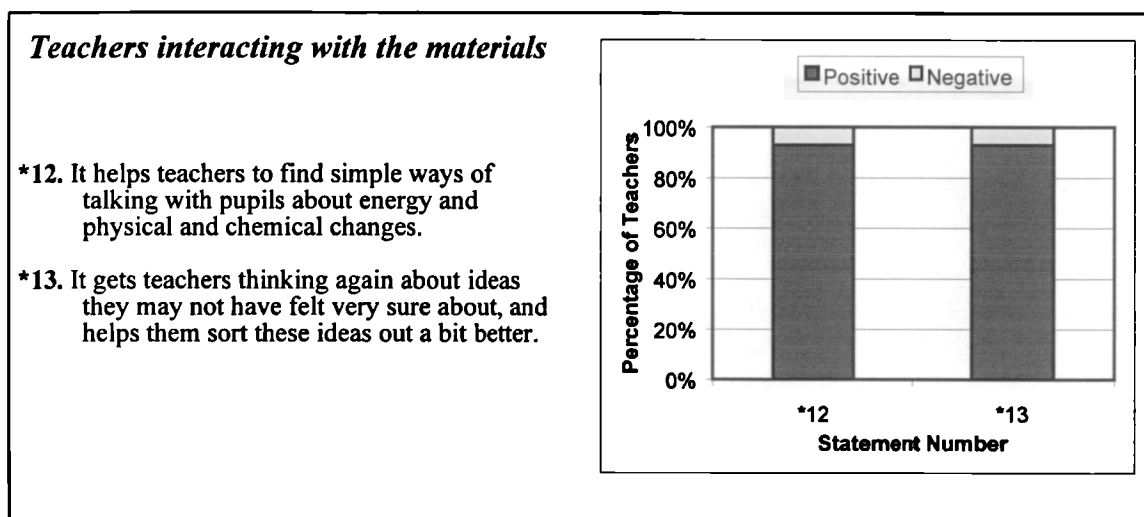


Figure 10.5 Teachers' views about interacting with the materials

Finally, about eighty percent of the teachers thought that the materials could be used alongside existing schemes of work (S14), and that they could find good places for them in their own schemes (S15).

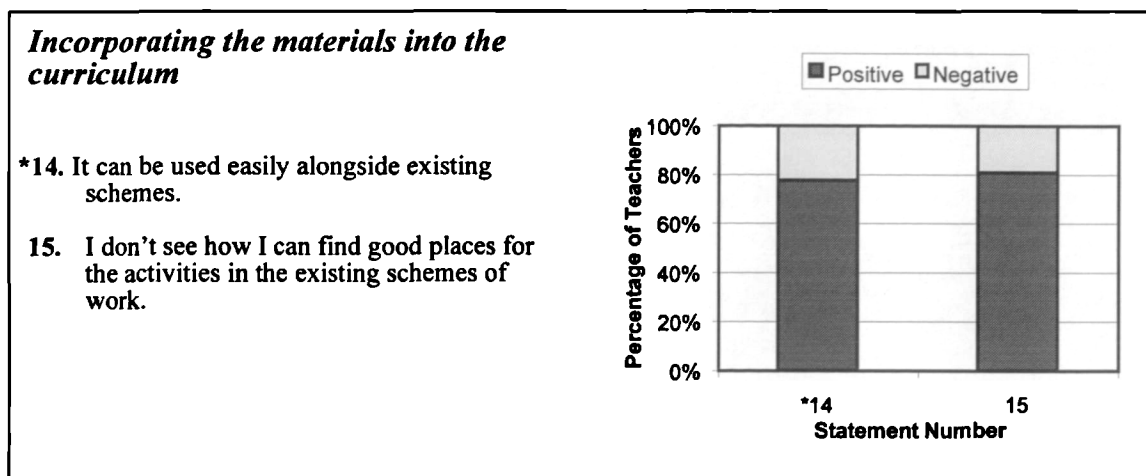


Figure 10.6 Teachers' views about incorporating the materials into the curriculum

Overall, it can be seen that the overwhelming majority of the teachers gave answers 'positive' to the project for those statements dealing with their general view of the new approach (statements 1-3 and figure 10.2); those relating the materials to practical experiences (statements 10, 11 and figure 10.4); those concerning whether the materials would help teachers and pupils learn better (statements 12, 13 and figure 10.5); and those about the ease with which the materials could be incorporated into existing schemes of work (statements 14, 15 and figure 10.6). 'Negative' views were only appreciably expressed in response to some of the statements concerning the way children would interact with the materials (statements 4-9 and figure 10.3). The major concerns here were that the materials might not be accessible to low ability pupils and/or those with language difficulties, that the vocabulary of the project might be special and/or non-scientific and that the pictures might prove too abstract for the pupils. It should be noted that there is a strong contrast here between the views of the teachers who have not used the project's materials and the two teachers who did use it, on how accessible these would be to low ability pupils and/or those with language difficulties.

10.3 Discussion of data from interviews and questionnaire

The approach: the science behind it

One obvious issue is whether teachers saw the materials as raising fundamental scientific issues. All the teachers, both those interviewed and those who attended the INSET, agreed that the ideas introduced by the materials are fundamental and can help link together many parts of science, up to GCSE and beyond.

The head of science in the school in which I carried out my fieldwork, put it very nicely:

“They’re fundamental because they’re probably essential ideas to understanding and that’s what I found very satisfying about it ... none of it has been a waste of time.”

But what did the teachers perceive as the main objectives of the approach? How many of them did really see the novelty of introducing Second Law ideas to describe change in a language suitable for pupils at the start of secondary school? Surprisingly, none of the teachers interviewed explicitly identified the ‘knowledge’ objectives of the approach. While most of the teachers who answered the questionnaire thought that the project is more than a different approach to teaching certain things, but also introduces new ideas, the teachers interviewed seemed to see it either as

“a different approach to teaching something that’s not being taught very well at the moment”

or new, in the sense that it is trying to get the pupils to understand things more deeply at an earlier stage than they would expect them to. They mainly saw the materials as helping pupils to attain a better understanding of what is happening in a change,

“...what is going on, sort of - if you like - behind the scenes -what is causing things to happen and why things happen, instead of just what happens...”

and further, as promoting pupils’ critical and abstract thinking. The comment:

“To get them to increase their conversation and hopefully their abstract thinking and therefore in turn raise achievement.”

is how the head of science summarised what she thought as the main goals of the approach, voicing among others one expectation and concern all the teachers seemed to have about the approach. Does it help the pupils achieve better examination results? Because, as one of the teachers cynically put it:

“Everything now is seen as a vehicle for achieving better examination results. Nobody is interested any more in pupils’ understanding.”

It may not come as a surprise that when thinking about the materials the teachers seemed to have strongly in mind the welfare of their pupils. Their priorities seemed to lie with the interests of their pupils both in the short and in the long term, sometimes maybe even at the expense of attending to the science knowledge that they are called on to teach. This is exemplified by the fact that almost one third of the teachers who completed the questionnaire thought that the ideas introduced in the materials are too general, whereas pupils need a lot of interesting particular things to

think about. One other possible explanation for the above response is in terms of the experience the teachers who completed the questionnaire had had of the materials. These teachers had been exposed during the INSET day to a great deal of ideas, mostly at a high level of generality. While they had been given the opportunity to look at and discuss some of the pupils' activities, they had also spent significant time acquainting themselves with the science behind the approach, and with the materials the project has produced for the personal use and interest of teachers. So, it is reasonable to assume that this experience affected the way the teachers responded to the questionnaire and more particularly the way they viewed the ideas introduced in the approach. Their perceptions of the difficulties were not all shared by the teachers who had used the materials. For example, the head of science pointed out:

"You need to generalise, I mean that's intelligence after all, being able to transfer ideas onto a new situation, if you can't generalise it's very difficult to do that."

Children interacting with the materials

Under this subheading I examine what the teachers thought of the means the project chose to realise its objectives, and in particular how well they thought that their pupils would cope with the activities, the vocabulary used and the pictures employed to encourage abstract thinking.

Almost all the INSET teachers thought that the materials would keep children active and busy, discussing and thinking. The teachers interviewed were also of the same opinion, and moreover praised highly the value of the materials for provoking discussion which could bring thinking and learning.

As to whether the materials are accessible to pupils of low attainment, and can help ones with language difficulties the INSET teachers were equally divided. However, the teachers interviewed, who had used the materials in a school whose pupils were on the whole of modest achievement and had at least a dozen first languages between them, seemed to think that the materials had not discouraged pupils of low attainment. They also felt they may be beneficial to pupils for whom English was a second language. For example, the head of science said:

"It's given those students confidence to speak about it in their own language, because the picture is common to both languages."

What all teachers seem to agree on, is that the activities challenge the higher ability pupils to think hard. One teacher explicitly said:

"I think some of it challenged (one of my best pupils). It was good for him - he would have to think about it. When he was writing his own examples he'd have to sit and think about that."

And the same teacher, summing up her argument about the suitability of the materials for different ability pupils:

"That's why I like it so much. Because it extends the ones that can do it without a problem and every single kid gets something out of it, even if it's just putting, sticking one of the pictures in the right place, grouping it in the right way."

Three quarters of the INSET teachers saw the work as an accessible way of introducing the particle nature of matter for Years 8 and 9.

All the teachers interviewed agreed that some of the pictures used in the approach are very abstract and have too many conventions. In particular, two thirds of the teachers who filled in the questionnaire worried that the pictures would prove too difficult for the pupils to make sense of and use them. However, the teachers who had used the materials pointed out that the pupils would be able to make sense of the pictures if the teacher spent some time regularly explaining and reinforcing their conventions. Another teacher remarked that one spends a lot of time teaching the pupils to use the pictures, but added:

"But the pupils whose language is poor or bilingual in the end probably get a higher understanding than they would repeating the exercises without using pictures. So I think in the lower school the benefits outweigh the problems."

Another statement the teachers had to think about referred to the vocabulary used in the materials. Again here, the teachers seemed to be equally divided on whether there is too much special and non-scientific vocabulary. The teachers interviewed acknowledged as well that many of the words used in the materials carry a specific meaning which sometimes refers to *"a huge bunch of understanding"*; this could be seen to some extent as facilitating communication, but also carries the danger that a simple use of these words by the pupils conveys the - wrong sometimes - impression *"that they understand what the whole package means"*. Other dangers a special vocabulary holds are that

"...the children can't find a book where they use words like concentrating and spreading out ... if the children want to go home and learn, it won't make any sense."

and pupils who are absent for more than one lesson get left behind quite quickly.

Relating to practical experiences

The statements here attempted to prompt the teachers to reflect on how they saw the activities suggested in the materials relate to the practical experiences the pupils are meant to have in the classroom.

One statement in particular presented the teachers with the false dilemma of which is better: some practical experiences or work comparing pictures and talking about them. Two thirds of the INSET teachers denied that practical experiences might be better, while the teachers who had used the materials were clear about the need for a balanced use of both.

Furthermore, all but one or two of the INSET teachers and all of the teachers interviewed found easy to see how some of the activities could build on practical work. Moreover, two of the teachers interviewed maintained that the activities not only could follow and build on practical work, but could also very successfully pave the way to it. In the words of one of them:

"It's easier in fact to see how it fits in beforehand often. And then getting the kids to do the practical work and to be able to describe in more detail what's happened."

Finally, the head of science, commenting on the relationship between practical work and understanding, expressed the view that practical experiences are not *a priori* beneficial for the pupils, but they could often prove confusing and repetitive, and added:

"There is no point in doing a practical if there's not been a lot of talk about it to start with, in my opinion, because very often it's just either you're proving something which is a waste of time anyway, proving something you've already understood...or er...you're doing something in a vacuum without the knowledge and understanding."

Teachers interacting with the materials

Teaching materials cannot be evaluated only from their benefits for pupils. It is also very important to find out what the material does for teachers. Does it help them in the classroom, and moreover, does it satisfy them intellectually, that is does it offer a challenge for their own ideas, and help them to sort them out a bit better?

All but very few teachers thought that the materials got them thinking about ideas they might not have felt very sure about, and helped them sort out these ideas a bit better. They also agreed that the materials provided teachers with simple ways of talking with pupils about energy and physical and chemical changes. One of the teachers who had used the materials expressed the same idea as follows:

"Because it's sort of reinforcing the same ideas the whole time, you know using simple vocabulary, I think the very simple.... yeah all of those things are very difficult at times to talk about or get children to understand, especially the ones that have a lower ability."

However, for another teacher this feature of the materials was not perceived as helpful or interesting, because according to him there already existed simple ways of talking about energy and change.

Most of the teachers who had used the materials extensively, agreed that the materials had made them think hard and understand better some of the ideas they had been teaching before. One of the teachers explained this in the following words:

"I found it makes me...really understand the ideas behind a lot of the things that you're meant to be teaching them anyway, you know like what's the point of this because you tend to do lots of isolated sort of bits and pieces especially in for example the energy topic and you don't really see a progression or a theme and you definitely do when you're using those materials. You have to use your brain."

The head of science saw potential in the materials for making teachers think about ideas fundamental to science.

"There are areas which are obvious that people have to come to, but then fundamental ideas about energy changes or about particle theory, maybe we're a little bit more nervous about asking about those because that would seem as if we hadn't really got our own basic science right. I found it very interesting particularly the idea with one change driving another. I found that very interesting and sorting out ideas... for myself."

Incorporating the materials into the curriculum

Finally, the last group of statements refer to the fact that the materials do not constitute a whole course but are intended in their design to be incorporated flexibly in existing schemes of work.

More than eighty percent of the teachers who completed the questionnaire thought that the materials could be easily used alongside existing schemes of work, and more than three quarters of them saw how they could find good places for the activities in existing schemes of work.

Most of the teachers interviewed had actually had the experience of integrating some of the activities in their schemes of work and were also very positive about its feasibility:

"And you might be teaching those in different orders in reality, but that wouldn't matter, I don't... I wouldn't think, because they're not sequential. So it's not a problem and I found that they fitted in very very easily, especially the Materials work [...]"

The head of science however, also acknowledged the time commitment and effort required from the teachers if they wanted to get acquainted with the approach and use it. She expressed that worry very realistically in the following words:

"There's a problem in that staff have got a lot of work to do and you're asking them to learn something extra, yet something else, and then maybe to them that's not a priority you know, and since they've done it successfully in their opinion another way they might just stick to their other way."

10.4 Summary

Overall, teachers' first reactions to the innovations were positive. They seemed to think that the new materials could fit with existing curricula, as intended, and that they would challenge pupils' thinking as well as their own. Their main areas of concern were, as one could have expected, the abstract pictures and nomenclature introduced by the project, and the accessibility of the materials by pupils across the ability range. Those teachers, however, who had used the materials with pupils were less worried about these aspects, since they had found that pupils were able to understand the approach and work with the new materials much better than they had anticipated. Moreover, since on the whole the pupils with whom they had used the materials are of below average ^{attainment} nationally, their positive attitude is an important factor to take into account.

CHAPTER 11

Conclusions

11.1 Introduction

This chapter discusses the conclusions of this study in connection with the research questions presented in section 5.5.

11.2 Answers to research questions: Pupil dimension

About the curriculum innovation

11.2.1 Is the language used by the project accessible to pupils at the beginning of secondary education? (R.Q. A1.1)

One of the novelties of the project's curriculum materials is the use of everyday expressions to describe changes. The issues here arise from the fact that these expressions, rich with everyday macroscopic connotations, are meant to capture difficult thermodynamic ideas. The terms 'spreading out' and 'bunching together' for example were assigned to descriptions of changes in concentration, the terms 'joining' and 'splitting' to descriptions of chemical change and the expressions 'it just happens by itself' and 'it doesn't just happen by itself' were used to describe ~~spontaneous and non-spontaneous~~ changes respectively.

Were these expressions accessible to the pupils? There are at least two issues raised by this question.

Usability of project's language

One is whether the pupils could and were willing to use the expressions to communicate their ideas. The evidence here is unequivocal. The great advantage of the project's language is that it is easily adopted by the pupils. During the implementation of the intervention the pupils never expressed objections and, on the whole, did not show reluctance to use the suggested terms when they were prompted to do so; by the end of the year, some pupils even used them spontaneously in their explanations of change (see section 7.5 - Comparison of Y7D with Y8A).

Agreement with intended use of project's language

However, a second more important question is whether the pupils used these terms and expressions in the intended way. The answer here is not so straightforward. The

fact that the expressions were simple and almost everyday ones meant that pupils could also use them in less desirable macroscopic descriptions of changes. For example, in the previous chapters we saw pupils often using the terms ‘spreading out’ and ‘splitting’ to talk about the ‘separation’ of two objects instead of using them to account for what happens to particles in the relevant processes.

Relative difficulty of suggested terms and expressions

Were the project’s terms and expressions all likely to be used in this undesirable way? It seems to me that the evidence suggests not. Considering in particular the main terms used with the Year 7 and 8 pupils as part of the curriculum intervention, it seems, rather, that these can be put in three distinct groups according to how close their use was to the intended one. In one group there are the expressions which describe energy changes, such as ‘energy spreads out / bunches together’ or ‘energy escapes / is stored’; these seemed to present the least difficulties to the pupils and were on the whole employed in the intended way. In another group, there are the expressions which describe material changes, such as ‘spreading out / bunching together’ and ‘joining / splitting’; these were often used inappropriately, but less so by the end of the intervention period. In particular the terms ‘spreading out’ and ‘bunching together’ were increasingly used more consistently and desirably in pupils’ explanations of change throughout the year. Finally, in a third group there are the expressions of *spontaneity* ‘it just happens by itself’ / ‘it doesn’t just happen by itself’. These worked on the whole the least successfully, although there was here also a small shift towards more sophisticated uses of them by the end of the period under consideration. There is little evidence that the pupils related the decision of whether a change happens by itself with what was thought of as happening to the particles and energy of the system. Rather the expression ‘it happens by itself’ seemed often to suggest to them that they had to look for a change which happens ‘naturally’, or in which no human action is seen to take place.

Having made the above categorisation, I want to mention two factors which should be taken into consideration when interpreting these groupings. The first factor is that not all the above expressions were given equal treatment in the materials used in the intervention, in terms of time devoted to them, or variety of contexts in which they were employed. This is important because one would expect that the use of an expression improves with time - the more the pupils use it and the more contexts they see it applied to. Indeed this was notably the case, as mentioned before, with ‘spreading out’ and ‘bunching together’ whose use was revisited and extended systematically throughout the Year 7 materials.

The second factor is that these expressions encapsulate difficult ideas. Although in this section I have dealt with the problem of the accessibility of the project's language rather than with that of its ideas, the two cannot be perceived in isolation. In other words, this language cannot pretend to be a panacea for concepts whose difficulty is well established. The difficulty the pupils had with the correct use of the above expressions should be thought of ^{also} as being associated with the difficulty of the ideas behind them.

Possible conflicts in the use of proposed language

There may be however another, subtler, point to be made in relation to these phrases. In their attempt to express some powerful thermodynamic ideas in simple words they may have been too successful and confounded the borders between scientific and everyday language. Pupils may oscillate between the two without realising it. As a consequence, they may often appear to be using the project's phrases in a desirable way, without in fact doing so. Teachers would need to be vigilant; they would need to encourage the intended use of the suggested expressions by identifying explicitly both desirable and undesirable uses.

11.2.2 How do pupils manage to make sense of and use the abstract pictures? (R.Q. A1.2)

Another novelty of the project's approach is the use of abstract pictures as a tool to help pupils generalise about change. A potential problem is that pupils may not in fact be able to move beyond the picture; the picture itself may become a source of difficulty and an additional obstacle to abstraction. The data were however quite conclusive that this problem did not become such a significant issue as to detract from the intended use of the project's abstract pictures.

Relative difficulty of abstract pictures

The pupils on the whole did not have any great difficulties in making sense of the abstract pictures and using them both in the project's activities and in the ensuing interviews, once the conventions had been explained to them. Naturally, there were some abstract pictures that presented more difficulties than others. In Year 7, these were the ones depicting the air pressure in different containers, and the ones representing thermal changes with the aid of thermometer icons. In the discussion of the Year 7 pupil case studies (see section 6.4) I refer to the cognitive demands I think the use of these particular pictures made on the pupils. In Year 8 the more problematic pictures proved to be the ones depicting 'chemical springs'. Again, the problems the pupils faced with these pictures and possible causes for these are

discussed more extensively together with the rest of the findings for the Year 8 class (see section 9.5).

A general observation concerning the problems the pupils appeared to have with the abstract pictures is that with the exception of the ‘chemical springs’ pictures, the difficulties arose mostly in conjunction with some of the more specific and specialised abstract pictures which appear in a small number of activities, rather than with the more general abstract pictures which depict the bigger ideas of the project. Indeed, the abstract pictures showing matter ‘spreading out’ and ‘bunching together’ and showing energy ‘spreading out’ and ‘bunching together’ due to temperature differences were adopted very easily and were used overall quite successfully.

Kinds of difficulties with abstract pictures

Some difficulties seemed to be related to the specific characteristics of the drawing of the abstract pictures. After all no picture can avoid the specificity of its drawing - including abstract ones. In almost all of these cases, the problems arose when the pupils failed to abstract from the depicted features the intended ideas and interpreted them too literally. On the whole, these interpretations were infrequent and erratic and most often suggested difficulties with the ideas represented by the pictures rather than any systematic problems with the pictures themselves. Consequently, most of the time they did not seem to constitute obstacles to pupils’ learning, but rather to be helpful indicators to teachers that the depicted ideas needed re-visiting. There is perhaps one exception to this; a case where the misinterpretation of the pictures resonated with a misconception that the pupils had about the phenomenon and as a consequence seemed to help to make this misconception stronger. The case in point was the depiction of a change of substance by a change in the shading of the particles in the pictures, which seemed on several occasions to reinforce pupils’ misconception that a change in the colour of a substance indicates on every occasion a chemical change and *vice versa*. However, the designers of the materials were aware of this problem and used these pictures only as an introduction to chemical change; in further activities they were replaced by the pictures showing particles joining and splitting.

As I have already hinted at and as could be expected, the difficulty of an abstract picture was strongly linked with the difficulty of the idea depicted by the picture. The fact that the ‘chemical springs’ pictures, for example, proved the most difficult for the pupils to use appropriately, especially in the interviews, I consider undoubtedly associated with the well-known difficulty of the ideas they represented.

The difficulties I have mentioned so far are mainly related to the adequacy of the abstract pictures to represent particular processes (e.g., chemical change or energy flow due to chemical potential differences) independently of their context of use. There are, however, also difficulties with the abstract pictures that seem to derive more directly from their use to represent these processes in *specific situations*. I am referring to the difficulties that arise in the context of matching one situation, described either in words or by a combination of words and a schematic picture, to the abstract picture which best represents it. This activity does not only require that pupils read properly the conventions of the abstract pictures, but also that they abstract the relevant processes from the given situations. Some of the undesirable uses of the abstract pictures were due to pupils being unsuccessful in achieving these abstractions. In a following section I will deliberate on how well I think the pupils managed this.

However, even when pupils identify the relevant processes, they still may not be able to describe them in ways which are appropriate from a thermodynamic perspective. Thus, the structure of the project's abstract pictures, which is proper to the fact that they represent thermodynamic processes, introduces a further complication into the matching activity. Pupils have to identify a 'Before' instance and an 'After' instance in a given change before matching it to the appropriate abstract picture, since the latter consists of a pair of 'Before' and 'After' pictures as well. The difficulties that this requirement created became more apparent in the pupil interviews where there were fewer contextual clues to help the pupils with the matching task. On several occasions in these, the pupils struggled to agree on a choice of abstract picture, since they each considered different 'Before' and 'After' instances for the same change. This was usually in relation to the matching of changes about which the pupils had a rich knowledge (e.g., 'getting salt by evaporating salt solution' or 'melting wax'). In the majority of these cases the pupils failed to identify what the issue behind their different choices was; in the few cases where they did, stimulating discussions ensued about it.

Summary evaluation of abstract pictures

Considering their overall use, the abstract pictures were rather successful in helping the pupils to identify the essential processes they should focus on in a given change; much more so than the corresponding verbal prompts used on their own. However, it was also noticed that in some cases the pupils seemed to respond merely to the verbal prompt that accompanied the picture and did not adhere to the conventions of the picture. This again was noted in the context of the pupil interviews, rather than in the context of the project's activities.

About pupils' learning when using the innovation

11.2.3 Do pupils using the materials start to appreciate that change is caused by *differences*? (R.Q. A2.1)

To say whether at the end of the intervention the pupils grasped the key idea of the project, that is, that change is caused by *differences*, is an impossible task. The authors of the innovation clearly state that, whereas this idea has guided the design of the materials and has provided a rationale for their coherence, it is phrased at a very high level of generality, inappropriate for pupils of this age. Consequently, this idea does not figure explicitly in the curriculum materials. The aim is that pupils might be led to appreciate this general principle after some years of using the proposed approach consistently in their study of processes of change. So, at the end of the less than one academic year that the intervention lasted one would not expect to say anything really substantive about pupils' progress in this respect. However, since the idea of 'differences' is so essential for the project, I thought it would be important and interesting to look at whether there are any signs that the pupils moved towards it.

I will very tentatively suggest that there are two ways of interrogating the data for these signs. One is to ask if the pupils in their explanations of change seemed to acknowledge in any way that 'differences' drive change. The other is to look for whether the pupils started appreciating that changes where differences disappear are spontaneous changes, or in the project's terms 'just happen by themselves'. In my opinion, at an elementary stage such an awareness could be thought of as a precursor of the desired idea.

References to 'differences' as causes of change

Regarding the first question, there was some positive evidence in both year groups. This positive evidence refers more to temperature differences than to concentration differences. In the Year 7 pupil case studies I mentioned that some pupils in their accounts of changes of state attributed them more or less explicitly to differences in temperature between the system and its surroundings. In the data of the Year 8 class, on the other hand, there were more than a few examples where the pupils acknowledged that the observed changes of temperature and accompanying energy flows were due to temperature differences which disappeared in the process. The case for concentration differences is weaker and is mainly based on the Year 7 data, since the corresponding ideas did not feature as prominently in the Year 8 teaching intervention. The pupils clearly progressed in identifying concentration differences

and in reasoning about their disappearance. However, it is not clear to me whether they saw these differences as driving the changes.

Overall, I consider the data as indicating that the pupils started making some use of the intended idea in their explanations of change. Moreover, the fact that temperature differences were the first, and perhaps easiest, to be acknowledged by pupils, could have been expected; not only because these were promoted more persistently in the materials used in the two classes, but also because of their strong and direct relationship to pupils' previous experiences.

Did pupils see that differences disappear spontaneously?

Considering the second question, the evidence is more subtle and open to interpretation. My general impression is that the pupils tended to reason that changes in which some kind of difference got destroyed 'just happen by themselves'. More particularly, I noticed in the pupil interviews that in some cases the pupils appeared to causally link in their explanations their choice of an abstract picture showing a process arriving at equilibrium with either the abstract picture or the phrase 'it just happens by itself'. Moreover, looking at all their choices of abstract pictures, it appears that on the whole the situations which had been matched to the abstract pictures showing energy 'escaping' (either due to temperature differences or to chemical potential differences), or to the abstract picture showing something spreading out, were more likely to be thought of as spontaneous than as non-spontaneous. This was the case independently of whether these situations were matched to the appropriate abstract pictures in the first place. However, I do not assume that this reasoning was conscious in any way.

It is likely that the pupils' choice of pictures was affected by the design of the abstract pictures, which purposefully emphasises the destruction of a 'difference' and the attainment of equilibrium. The abstract pictures convey this emphasis by showing particles at the start concentrated in the centre of the picture and then evenly spread out; by showing the system and its surroundings in different shadings 'Before', and in the same 'After'; or by showing a spring stretched getting back to its normal length. Associating such processes with spontaneity is clearly important. Moreover, I will speculate that it is *essential*, if pupils are eventually to see these processes as the necessary driving mechanisms of other changes which 'do not just happen by themselves'. The data seem to suggest to me that the pupils in the study started making this association, even if unconsciously.

Summarising the above two points, although the duration of this intervention does not permit conclusive answers, I believe that there is some tentative evidence that pupils using the materials start to appreciate that change is caused by ‘differences’.

11.2.4 Do pupils, as a result of the teaching approach, become more able to identify the essential features of changes and draw similarities and differences based on these? (R.Q. A2.2)

One of the claims the project makes is that the novel approach with the aid of the abstract pictures will help pupils to identify the essential features of changes and to make clearer the fundamental similarities between many of them.

Right from the start of the intervention the pupils seemed to manifest two kinds of difficulties when asked to reason about a particular change (e.g., in the context of a project’s activity, or more expressly in the context of the interview tasks).

Focus on what is happening in a change

At an elementary level, one difficulty was of executing the required task, that is, of focusing on what was *actually* happening in the given change, rather than on their participants and on what they *could* do or what *might* be likely to happen to them. This difficulty clearly is a very important one, as it is relevant to the teaching of science in general and not only to the teaching of this innovation. Now, the analysis of the data showed (see subsections 7.2.2.1, 7.5.1, 9.2.2.1) that by the end of the intervention the pupils in the study had progressed significantly with respect to this difficulty. Of course, in a way this progress was expected; as pupils mature through schooling they become better at identifying what is important for and required by a specific task, and learn what counts as a desirable explanation in a science lesson and what does not. However, the important result here might be that apparently the pupils who had been exposed to the intervention appeared to be more adept in considering what was happening in the given changes than pupils of approximately the same age who had not (see section 7.5.1).

Events versus processes of change

Another problem with pupils’ reasoning about change was that even when they focused on what is actually happening, they often treated the situations presented to them as ‘events’, i.e. looked at them superficially as macroscopic incidents, and not as examples of processes of change. A possible factor contributing to this is that most of the situations in the project’s materials were chosen to depict familiar everyday changes. This further meant that they triggered a lot of everyday associations for the pupils, associations which most probably did not require a deeper understanding of

the processes involved. However, the project's materials are not any different in this respect from most textbooks for this age group of pupils.

This problem is again relevant to scientific reasoning in general, but as one can imagine, is a real obstacle to abstraction. So the question to be posed here is whether the novel approach helped the pupils to focus on the physical and chemical processes involved in changes, and in particular to identify the changes in concentrations of matter and energy.

Abstracting processes with and without the use of pictures

In my mind there is no doubt that the use of abstract pictures in combination with the matching task, as mentioned in a previous section, helped the pupils to concentrate on the essential features of the changes and on the intended processes. Having said this, there is also an abundance of evidence that the pupils in many of the matches they made, especially as part of the interview tasks, perceived changes as events. An example of such an instance is when a pupil matched 'ice forming on a pond' to the picture of 'spreading out' because, as s/he said, ice is spreading out on to the pond when it forms. Now, did these accounts improve in the course of the intervention? The data seem to me to suggest that for the situations about which the pupils received some teaching, they did. The pupils seemed to match them on the whole to more appropriate abstract pictures, but most importantly they accounted for them in a more desirable way. This shift was not equally observed with the other changes that the pupils had not discussed in their lessons using the project's materials.

Did the pupils produce these more desirable accounts spontaneously, when they were not prompted by the abstract pictures? Evidence comes from the analysis of the first of the interview tasks, where the pupils had to pair situations based on their similarity and then to explain their choices (see sections 7.2 and 9.2). It seems to suggest that the pupils did not progress in their spontaneous accounts significantly in the course of the intervention. These accounts seemed to fall short of what the project would wish for, but to be still comparable with the ones given by their peers who had been taught in the traditional way.

Abstracting similarities and differences

The difficulties discussed above clearly played an important role for the kind of similarities and differences the pupils identified both between changes and between a change and an abstract picture. So, when they focused for example on the participants of the changes, instead of the changes themselves, the similarities (and differences respectively) identified referred to them or to their properties. Similarly, when the changes were perceived as events, the similarities identified were also at

this level. As a consequence, what has been asserted above about the progress of the pupils in relation to these two difficulties is valid also here. By the end of the intervention, the pupils were more adept in drawing similarities between changes based on what they perceived as happening in them. On the other hand, they were *not* better at identifying these similarities to be changes in the concentration of matter and/or energy, when unaided by the abstract pictures.

In the case of seeing similarities between the situations and the abstract pictures, I have already mentioned the difficulties arising from the superficial interpretation of the features of the abstract pictures. Similar difficulties also arose when the features of the ‘real-world’ schematic drawings which depicted the changes were interpreted superficially. Examples of this include one pupil matching the situation of ‘crystal forming in copper sulphate solution as it cools’ to the picture of ‘spreading out’ because s/he saw “*all those dots*” depicting the crystals in the drawing as spreading out. Although, these kinds of explanations were few, they point to the issue I have already addressed in relation to the use of abstract pictures. This is the issue of the specificity of a picture, an issue which though not related to the ideas the innovation wishes to promote, is very much related to the means it chose to promote these ideas.

11.3 Answers to research questions: Teacher dimension

About the curriculum innovation

11.3.1 Do teachers see the materials as raising fundamental scientific issues? (R.Q. B1.1)

There was total consensus among the teachers that the scientific issues addressed by the project’s materials are fundamental. However, although it was unclear to me whether the teachers fully grasped the scientific background and provenance of the ideas introduced by the project, they appreciated that the materials address the important issue of *why* changes happen as well as promoting pupils’ critical and abstract thinking about *what* happens in changes.

11.3.2 What do teachers think of the means the project uses to realise its objectives, i.e. the activities, the vocabulary used and the abstract pictures? (R.Q. B1.2)

Teachers’ views concerning the project’s suggested teaching approach and its accessibility for pupils were not uniform. Whereas almost all the teachers in their evaluations agreed that the project’s materials encourage the active participation and learning of pupils, they did not all equally agree that the materials are accessible to

pupils of all abilities. More particularly teachers' views on this issue seemed to vary depending on the familiarity they had with, and on the use they had made of the materials. On the whole, teachers who had had only little exposure to the new approach and who had not had the chance to try it in the classroom expressed some scepticism about its applicability. They were concerned that the project's activities might not be accessible to low ability pupils; that the suggested vocabulary might be too special and non-scientific; and finally that the pictures used might be very abstract and have too many conventions. On the other hand, the teachers who had actually used the materials in the classroom not only vouched for their accessibility to pupils across the ability spectrum, but also maintained that the use of pictures had helped pupils with language difficulties to reach a better understanding than they would otherwise have done. Concerning the suggested vocabulary, however, they pointed to problems which might arise from it being at once 'common' and 'special' (see also section 11.2.1).

About teaching the innovation

11.3.3 Do the materials help teachers teach about energy and change? (R.Q. B2.1)

Almost all the teachers questioned and interviewed thought that the materials provided them with simple ways of talking with pupils about energy and processes of change. Moreover, as mentioned before, all teachers and most importantly those who had used the materials, praised the pupil activities for provoking discussion which could encourage thinking and learning.

From my own observations of the two teachers who taught the approach I can attest that both seemed to have very few difficulties in using the project's materials in their teaching, even when there had been very little time to acquaint themselves with the activities before the lessons. What they appeared to struggle more with, especially at the start, was the use of the project's vocabulary; only occasionally did they have problems with the use of the abstract pictures. Moreover, as one would expect, both these uses improved with time as teachers got more familiar with the new approach and felt more confident using it.

11.3.4 Could teachers find good places for the activities in the existing schemes of work? (R.Q. B2.2)

Most of the teachers were very positive that they could find places for the project's activities in the existing schemes of work. It is unclear however whether in saying

this they were referring to an occasional and sporadic use of the project's materials or to a consistent and progressive integration of them in the school's Key Stage 3 and 4 schemes of work. Both kinds of use are professed to be desirable from the project's point of view; however, it is only the latter that can be expected to bring more substantial changes in the way pupils reason about energy and change.

For the purpose of this research, the selection of the project's materials to be used and the sequencing of them were essentially suggested by the authors of the materials and consequently endorsed by the two individual teachers who volunteered to trial them. As a result, there are no empirical data concerning the spontaneous or unassisted use of the materials by teachers. There is however relevant evidence from work done for a trans-European research project ('Science Teacher Training in an Information Society'). This suggests that a consistent and full integration of the project's materials in a school's schemes of work might well be problematic (Stylianidou and Ogborn, 1999). As part of that work, case studies were conducted in two further schools which made use of the project's materials. In both cases this use resulted in the transformation of the innovative approach in interesting and important ways. In one school only certain ideas of the new approach were adopted and these were transformed to suit what had been already in the schemes of work, and there were possible contradictions between the new and the old ideas. Full integration of the project's materials had been deferred since the required level of commitment and co-ordination across the school's science department had not been present. In the second school, the situation was very different. The science department was committed to both the ideas and the general framework of the new approach. However, instead of incorporating the project's materials with other teaching materials so that the induction to the new approach would happen progressively, they created a new topic in Year 7 for the exclusive use of the materials. In this topic the pupils got presented with the basic ideas, terms and abstract pictures of the approach in one large dose and in isolation of any other practical or more familiar teaching activities. This use of the materials was not intended by the authors of the materials who clearly state in the booklet 'Activities for the classroom' (Boohan and Ogborn, 1996a, p1) that "*the activities do not make up a complete teaching pack for a topic*", and further describe them as designed to be 'slotted into' *existing* schemes of work. It is of course a matter of judgment who is right, or whether both alternatives are viable.

About teachers' learning when using the innovation

11.3.5 Do the materials satisfy teachers intellectually, that is do they offer a challenge for their own ideas, and help them to sort them out better? (R.Q. B3.1)

Almost all the teachers agreed that the project's materials had got them thinking hard about ideas which are fundamental to science, and which they might have not felt very sure about. They further reported that as a result of this interaction with the new approach they felt that they had sorted out these ideas for themselves rather better.

For my part, I have witnessed and in some cases participated in a few very lively discussions amongst teachers provoked by the project's activities and thus I can assert that the new approach does challenge teachers' own ideas both about the role of energy in processes of change, and about how one could talk about it to pupils.

11.4 Looking back: The project, the thesis and I

Eight and a half years after we first met, it is time for the project, the thesis and I to part. It is also time to look back at these years and reflect on who we were and what we have become.

The project

The project itself terminated in September 1995. It produced an innovatory approach and curriculum materials for teaching about energy and change to pupils aged 11-16, based on ideas from the Second Law of Thermodynamics. Until today the approach has not been widely taken up by schools, although it has been well esteemed in the international academic world. There are many reasons to which one could attribute this. In my opinion the most important of these have to do with the fact that the suggested approach and materials both challenge accepted ways of teaching and introduce new content. The combination of these two characteristics together with the absence of provision for systematic training of teachers in the new approach may account for its low uptake.

The thesis

The thesis grew up to be an intervention study with evaluative features. It is characterised by the close interactive relationship it had with the project and by the interpretive contextual framework within which the analysis was accomplished. I consider these characteristics as both this study's potential weaknesses and its definite strengths. They are potential weaknesses since they expose this study to criticisms over the reliability and validity of its results. On the other hand, they are

definite strengths, most importantly because the awareness of these characteristics called for the adoption of a multi-faceted data collection and analysis. In other words, a variety of data were collected for the same thing, but also a variety of analyses were conducted on the same data. Moreover, an explicit attempt was made to include enough information from the original data (e.g., by giving examples from pupils' responses) to allow readers to consider whether they would come to the same conclusions concerning the results.

The thesis provides results about the accessibility and usefulness of the new approach and materials to pupils and teachers, and also indirectly about pupils' conceptions of ideas concerning the second law of thermodynamics. These results suggest that the innovative aspects of the new approach were broadly accepted by both the pupils and the teachers who took part in the intervention. It is true that the pupils' progress was unequivocal only for the more modest of the project's objectives (e.g. in relation to temperature differences and energy flows), however, there was no question at any point that any of the pupils were affected negatively by the intervention, whereas it is certain that most of them profited from it in a number of ways.

I (as the researcher)

I, starting off from a positivist background on the basis of my degree studies in physics, in the last eight and a half years have grown to appreciate how complex, unpredictable and therefore fascinating is a study involving human beings. In the process, I learned that, like all studies, it requires approaching and thinking about the problem from different perspectives; taking risks and making interpretations; and aiming for the bigger picture without losing the detail.

Finally, looking back at my journey I cannot help thinking that Cavafy's (1990) poem 'Ithaka', appropriated already by so many people to account for their life 'journeys', epitomises this one as well. The poem finishes with the words:

*"Keep Ithaka always in your mind.
Arriving there is what you're destined for.
But don't hurry the journey at all.
Better if it lasts for years,
so you're old by the time you reach the island,
wealthy with all you've gained on the way,
not expecting Ithaka to make you rich.
Ithaka gave you the marvellous journey.
Without her you wouldn't have set out.
She has nothing left to give you now.

And if you find her poor, Ithaka won't have fooled you.
Wise as you will have become, so full of experience,
you'll have understood by then what these Ithakas mean."*

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