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ABSTRACT

This document presents the results of three studies about how children interpret observations of the biological phenomena of decay. The objectives of this report were to: (1) document and compare the ideas used by elementary school children in the United Kingdom, the United States, and Canada; (2) document how these ideas changed from age 5 to 16; and (3) consider how an understanding of student ideas is helpful to teachers and curriculum designers in planning science curriculum relating to decay and cycling of matter. The methodologies and aims of the work differ in each country but are cited as complementary. In the United Kingdom, two instruments were administered to a sample (n=292) drawn from state schools, in the age range 8-16. These instruments included a writing task and interview (with photograph props); and video tape viewing followed by writing task. In the United States, the population sample (n=149), age range 5-16, was privately interviewed and audio-tape recorded. In Canada, the video instrument administered in the United Kingdom was used with students (n=125) in grades two (age 7-8) and five (age 10-12). These students were interviewed after the video tape presentation. The results conveyed many explanations of decay phenomena that made scant reference to microbial decay and cycling of matter, with a high level of relevant experiences of decay phenomena reported by the majority of students at all levels. Educational implications discussed include: (1) curriculum design, (2) planning for teaching, (3) and the classroom environment. (Contains 18 references.) (MCO)

The ideas used by British and North American school children to interpret the phenomenon of decay: a cross-cultural study

John T. Leach , Richard D. Konicek and Bonnie L. Shapiro

Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, Ca.

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The ideas used by British and North American school children to interpret observations of decay: a cross-cultural study

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The first author apologises to N. American readers for his failure to attempt N. American spelling!

1 Background and Objectives

This paper synthesises work carried out independently by the authors, looking at the ideas used by children in England, the United States of America and Canada to explain their observations of the phenomenon of decay. The authors met while Drs. Konicek and Shapiro were visiting the Children's Learning in Science Research Group at the University of Leeds during the Spring of 1990. At this time the authors found that they shared an interest in the development of children's ideas about biological phenomena. Due to the high profile media coverage of 'green' issues such as waste disposal and composting, the topic of decay and cycling of matter was of particular interest. Since Spring 1990 the researchers have pursued individual but complementary research on the ideas about decay used by children in their respective countries.

The primary objectives of this paper are to document and compare the ideas used by elementary school children in the United Kingdom, the United States and Canada to explain the phenomenon of decay. Two related objectives are : 1) to determine the nature of the development of ideas about decay between various age levels in England, the USA and Canada, and 2) to consider how an understanding of student ideas is helpful to teachers and curriculum designers in planning the science curriculum relating to decay and cycling of matter.

2 The Research Perspective

A constructivist perspective informs the research. The basic assumption of this perspective is that children come to science learning with previously developed ideas that are used to interpret phenomena and events. We view these ideas as mental representations with which all school science teaching is interpreted (von Glasersfeld, 1989). Sometimes children's ideas may be consistent with the school presentation of ideas, but this is not always the case. In many instances children construct explanations which focus on the perceptually obvious aspects of a phenomenon, but miss out aspects that are crucial to a scientific explanation. Children may relate different phenomena in their explanations from the phenomena linked in scientific explanations. Children may not see the need to offer any explanation for some of the problems that are addressed during school science lessons - 'the world's just like that!' (Driver, 1985). Children may take different meanings from certain words than their science teachers (e.g. Bell, 1981). In some cases it is possible that children develop organised 'theories' to explain a range of phenomena that are strongly held by the child but in contrast to taught science (Carey, 1985). For reasons such as these, students may experience difficulty in learning certain ideas presented to them and may cling tenaciously to prior notions based upon ideas or experiences which seem more real to them.

If the learners' understandings are known to educators, more realistic teaching goals and learning experiences may be developed for students. If the starting points of learners are known, and the conceptual objectives of science teaching are clear, educators can better appreciate the intellectual demands on learners in particular topic areas and plan accordingly (Millar, 1989). These differences may require differing approaches to the construction of learning opportunities for students. Attention to the environment most conducive to meaningful learning is also of interest (e.g. Lemke, 1990).

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Further thoughts on the research perspective are included in section 8.

In this project, researchers have been interested in the development of student ideas over several years of schooling.

3 Rationale for the study

During the Spring of 1990 a research project was underway at the Children's Learning in Science Research Group to determine the development of children's ideas from age 5 to age 16 about a range of concepts relating to one Attainment Target of the British National Curriculum for Science[4] (Leach *et al.*, 1992). The conceptual focus of the study was cycles of matter, flows of energy and interdependence and classification of organisms in ecosystems. Information from the study was to be used by the National Curriculum Council to allow general performance indicators to be produced for children, and to inform teachers and other educators about the conceptual demands made on learners by this area of the science curriculum. The project was carried out in association with practising teachers on a consultancy basis. Methodology was thus designed to elicit the ideas used by children from age 5 to 16 about a range of ecological concepts, allowing comparisons between the explanations offered at different ages. Data were collected by interviews carried out by one researcher, augmented by written data from older pupils.

For the purposes of collaborative work between the authors it was decided to restrict our conceptual focus to children's explanations of the decay process and their knowledge of the association between this process and the cycling of matter in ecosystems. In particular, we were interested in the language used by children to describe their observations, their explanations of the cause of the decay process, their previous experience of the decay process and their ideas about matter cycling and conservation of matter as the decay process progressed.

A review of previous work on children's ideas about decay and cycling was undertaken to inform our selection of methodology and interpretation of data.

Instruments were designed to access children's ideas about decay and cycling while the authors were working in Leeds, though the administration of these instruments evolved according to the particular priorities of the individual authors. Drs. Shapiro and Konicek collected data in association with graduate students on Masters and Doctoral programmes and as such the design of the diagnostic instruments evolved from the original prototypes produced in Leeds.

Methodology developed at the University of Massachusetts was designed to inform about the development of children's ideas about the phenomenon of decay from age 5 to age 16. A related research question concerned whether familiarity with activities such as composting and the use of 'environmentally aware' language was related to the conceptual models used by children to explain decay. Data collection was carried out by a group of Masters and Doctoral Students and their Faculty Supervisor.

Methodology developed at the University of Calgary was based upon use of the Video probe developed and tested while Dr. Shapiro was visiting Leeds University. The intentions of the project were (1) to provide information about Canadian school students' ideas about decay during early years (age 7 -9) and later years (age 10-12) of elementary school; and (2) to organise information in such a way that it could be readily compared with findings from both the United States and the United Kingdom.

The research questions of the three authors were thus different. The primary objective of the work in Leeds was to document the ideas used by pupils to explain phenomena related to the cycling of

[4] The National Curriculum for Science (England and Wales) consists of 17 Attainment Targets at the time of writing. These contain general performance indicators for pupils between the ages of 5 and 16 in particular areas of science. This project focused on AT2: The Variety of Life. The National Curriculum Council is responsible for keeping the National Curriculum under review.

matter, flow of energy and interdependency of organisms in ecosystems, and how these ideas develop from age 5 to age 16. Work at the University of Massachusetts focused on the developing ideas of pupils about decay and cycling of matter from age 5 to age 16, and in particular whether children with different experiences of decay phenomena use similar ideas in this conceptual area Work at Calgary has focused on data from pupils between age 7 and age 11, examining the ideas used by pupils to explain decay phenomena. In particular, the research team was intrigued by the way in which teaching approaches in different classrooms resulted in differences in the ability of students to express and describe their ideas about the nature of decay.

In this paper related work on children's ideas about decay is reviewed. Methodologies used at the Universities of Leeds, Calgary and Massachusetts are then described. Results are presented relating to our research questions:

- What ideas do children use to explain decay phenomena? How do these change from age 5 to age 16?
- Is there a relationship between children's experiences of decay phenomena, the language that they use to describe these phenomena, and the conceptual models that they use to explain these phenomena?
- What are the sources of children's ideas about decay?

We conclude by discussing educational implications for curriculum sequencing and the design of teaching strategies.

4 Review of Literature

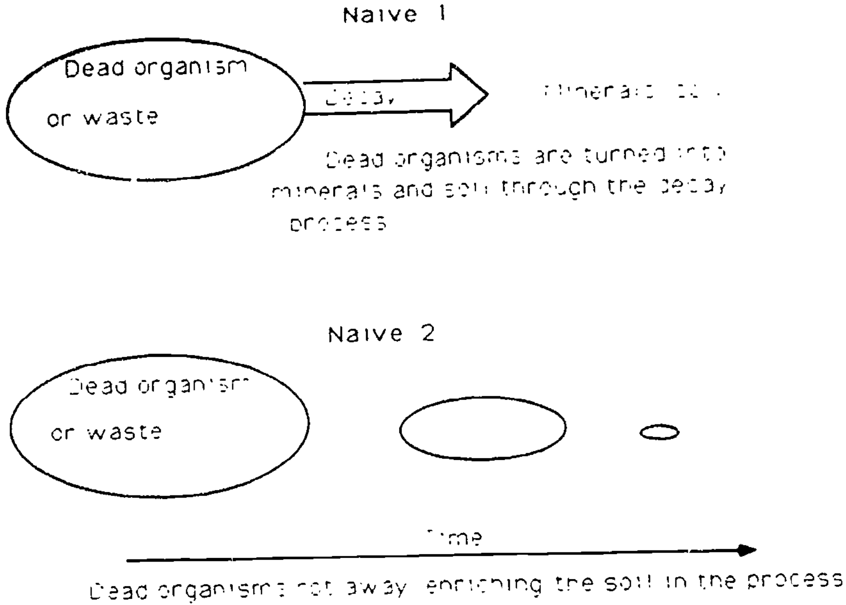
Little work on children's explanations about the decay process has been located. The following two papers were used by the authors to inform the design of the study and interpretation of the data.

Sequeira and Freitas (1986) looked at children's alternative ideas about decomposition. Pupils were aged from 8 to 13. The involvement of germs was mentioned by some pupils as being important to decomposition. Ideas involving total or partial disappearance were common, as were ideas where the decaying matter was said to have been eaten or worn out in some way. Very few pupils showed any concept of organic matter turning to mineral matter during the decay process. Sequeira and Freitas noted explanations of death and decay with anthropomorphic origins in young children, with older children being more likely to explain at the cellular level. They noted that many children assume that matter actually disappears during the decay process. There is progression towards cell-based explanations with age, the biggest shift being between the ages of 12 and 13 (possibly as a result of teaching).

In a further study Sequeira and Freitas (1987) compared children's explanations of the appearance of mould on bread to their explanations of a chemical change (the appearance of green copper oxide on copper metal). They noted that the words 'mould' and 'rust' were used by children in connection with both moulding and corrosion, and that the majority of the children did not think that mould was alive. A range of suggestions were made as to the cause of moulding. The action of physical external factors such as the sun or insects were suggested, as was the idea that moulding is an intrinsic property of bread (if you leave bread out then it will mould). Some pupils thought that mould accumulated on the bread from an external source whereas others thought that the mould came from within the bread in some way.

Smith and Anderson (1986) investigated the ideas used by seventh grade children (12 year olds) about matter cycling in ecosystems using a pencil-and-paper item prior to instruction and after instruction. They identified two naive conceptions used by children about decay, as illustrated in figure 1:

FIGURE 1: NAIVE CONCEPTIONS ABOUT DECAY (AFTER SMITH AND ANDERSON. 1986)



In the goal conception, decomposing organisms convert dead organisms to carbon dioxide, water and minerals. Some matter is transferred into the body of the decomposers. In naive conception 1 decay is seen as a process which does not involve decomposers. The matter from the dead organism is converted to minerals or soil. In naive conception 2 decay is seen as a gradual and inevitable consequence of time, enriching the soil in some way.

It should be noted that the items used by Smith and Anderson were used in connection with teaching on decay and cycling. Students in both the preinstruction and post-instruction data collection would therefore have been aware that the test item related to one particular part of the science curriculum. and this may have cued responses involving taught science concepts (Solomon, 1983).

5 Methodologies

As has been stated, the methodologies and aims of the work based in the United Kingdom, the United States and Canada were complementary but different They will therefore be described individually, noting similarities and differences in emphasis.

Due to differences in the grade and year numbers assigned to pupils of different ages in Great Britain and North America, results have been banded into four age groups, namely age 5 - 7, 7 - 11, 11 - 14 and 14 - 16.

5.1 Methodology - Leeds Study

Two instruments (termed 'Probes') were used to elicit children's ideas about decay and cycling of matter. The probes were phenomenological in nature (Driver and Erickson. 1983), and were administered to all pupils from age 5 to age 16 In this way, conclusions could be drawn about the development of pupils' ideas across the age range.

On the Apple Probe, pupils were presented with a colour photograph of an apple tree, with windfalls One windfall is presented as an enlarged photograph, in an advanced state of decay. Pupils in the 5 - 7 age group were presented with a real decaying apple to observe; experience suggested that older pupils were familiar with decaying fruit, and could respond to the photograph. Pupils' explanations of this phenomenon were probed, using questions such as 'What do you notice about the apple? Why do you think that that is happening?'. At the end of data collection, pupils were asked whether they have heard of microbes and germs in the context of decay. This probe was administered as a pencil and paper task, and also as an interview with individual pupils.

In the second probe, pupils viewed a short video sequence of fruit decaying, prepared by time-lapse photography. Their explanations of this phenomenon were probed, with particular emphasis on the fate of matter as the fruit is seen to get smaller. This probe was administered as a pencil and paper task, in which small groups of pupils worked collaboratively on answers to the focus questions.

The materials used for the Apple and Video Probes are included in the appendix.

These Probes were administered to 292 children in total, in the age range 8 - 16. The sample was drawn from 2 co-educational state primary schools and 3 co-educational state secondary schools around a large Northern industrial city. Children tended to come from families in lower to middle income brackets, and a small number of children in the sample had family origins in India and Pakistan

TABLE 1: DETAILS OF THE LEEDS SAMPLE

Age	Number in Sample
8 - 9	32 Apple Probe (32 paper and pencil; 8 interview)
10 - 11	29 Apple Probe (29 paper and pencil; 8 interview) 29 Video Probe (Paper and pencil)
11 - 12	56 Apple Probe (56 paper and pencil; 8 interview) 56 Video Probe (Paper and pencil)
13 - 14	51 Apple Probe (51 paper and pencil: 8 interview) 51 Video Probe (Paper and pencil)
14 - 15	86 Apple Probe (86 paper and pencil: 8 interview) 84 Video Probe (Paper and pencil)
15 - 16	38 Apple Probe (38 paper and pencil: 8 interview)

The data consisted of children's written responses on the response sheets (see appendix), and audio-taped interviews. Children's writing was coded according to the language used to describe decay, the causation suggested, the fate of the matter suggested during the decay process and the children's previous experience of decay. All interviews were audiotaped, and these interviews were used in designing the coding system finally used.

A sample of data were coded independently by two of the authors, achieving an inter-rater reliability of above 90%.

5.2 Methodology - Amherst study

A total of 149 children between the ages of 5 and 16 were interviewed. Subjects were subdivided into three distinct populations (urban, rural, suburban) with the intention that differences in familiarity with decay phenomena would be noted between the populations. There were 55 urban, 60 suburban and 34 rural subjects. Data were grouped into four groups by age, 5-7 years, 7-11 years, 11-14 years and 14-16 years. The urban population was taken from a small industrial city in western Massachusetts whose school population is made up largely of the children of recent immigrants, mostly Hispanic. This city has a large proportion of families using Federal ADC (Aid to Dependent Children) funds, awarded on the basis of *per capita* income. In short, the sample is taken from a city which is a smaller version of many major cities found in New England These children were sampled from public and parochial schools and from a local children's museum

The suburban population was taken from public schools in three towns adjacent to the urban centre Rural children were sampled from a rural area, which included some farms, and isolated communities ranging from 300-1000 in population These children were enlisted from public school and from personal contacts in local neighbourhoods

Each interview was scheduled to last about 20-30 minutes and was conducted privately, one to one and audio-tape recorded. In addition, illustration tasks were assigned to younger children to aid in their explanation of decay. These drawings were annotated by the interviewer as described by the children Interviewers also took detailed notes of children's responses as a backup to the recordings. A copy of the interview schedule is provided signifying questions and subsequent probes (see appendix) Suggestive phrases and words were strictly avoided so that the children's choice of language was not compromised.

All interviewers used a single prop which was a container of soil upon which sat a healthy, red apple Children were asked to explain what they thought might happen to the apple if it were left on the ground, for an extended period of time outdoors where it had fallen from a tree. Children were then asked for an explanation for their predictions They were then asked to project the process to a few weeks hence, and then a long time from now and finally when the 'process was finished'. Further probing questions were asked to clarify where the material had gone and whether or not it was still available.

Categories were developed for coding the responses based on prior pilot interviews and on those which were developed in Leeds. Data were recorded on coding sheets designed by the group Regularly scheduled meetings allowed for cross-team checks on interpretations of dialogue and subsequent coding for developing inter coder reliability. Information was coded on.

- language used:
- causes for the predicted changes
- conservation of matter
- explanations of cycling of matter ov-- ne and
- relevant experience

(At the same time we gathered data on wha. ildren might predict about the ultimate disposition of a dead mouse in the same environment This was designed to see if children thought differently about decaying animals than they did about plants. These data are still being analysed and are not discussed in this report.)

5.3 Methodology - Calgary study

The video Probe developed and tested during Dr Shapiro s visit to Leeds University was used as the basis for data collection in the Calgary study The videotape, a time-lapse sequence of a bowl of decaying fruit, was presented to students in classroom and small group settings Students provided written comment on the survey forms (see appendix) Large and small group discussions regarding student ideas about decay were conducted by Dr Shapiro and graduate students All discussions and interviews were audio-tape recorded and were transcribed for coding and to facilitate a search for patterns in student thought.

A total of 125 Canadian students were interviewed in urban and suburban school settings 71 students from Canadian grade two were interviewed (age 7-8 36 male. 35 female). as were 54 students from Canadian grade five (age 10-12. 36 male. 18 female).

The data consisted of:

1 Student drawings and written statements on probe response sheets

2 Transcriptions of small group. large group and individual interviews with students and teachers.

3 Extended response sheets to further probe students' familiarity with terms and the sources of their contact with terms.

Categories were developed to organise thinking about the Calgary children's ideas and to look for patterns in these ideas. The categories selected were compared with the categories used in the Leeds study. It was determined that for the purpose of comparison, use of the same categories would be helpful. As noted in the Leeds study, this included language used to describe decay, the causation of decay suggested, the fate of the matter mentioned during the decay process and previous experience of decay.

In addition to the coding of information from the study, the students and the data were revisited in several ways. Group and individual interviews were conducted to probe student awareness of the sources of their knowledge, the terminology which they spontaneously used to describe the phenomenon of decay, and the ultimate course of the process. The Calgary research team returned to the classrooms several times to follow up and to clarify responses, in particular to determine the sources of student knowledge and whether students actually understood the technical terms which they used. All of the children in the study were revisited and asked to give further information on specific terms and phrases which they used to respond to the probe questions. The intent of these extended probes was also to determine the sources of information and terms which they had used in the written survey and in their discussions with researchers.

6 Results and Discussion

The studies aimed to document the ideas used by pupils to explain decay phenomena, and how these changed from age 5 to age 16. In particular, we considered the familiarity of pupils with decay, the language used by children to describe their observations, their explanations of the cause of the decay process, their previous experience of the decay process and their ideas about matter cycling and conservation of matter as the decay process progresses. Results will be reported under these sections. The main data source in this section is the Leeds study, though data from Calgary and Massachusetts are also drawn upon.

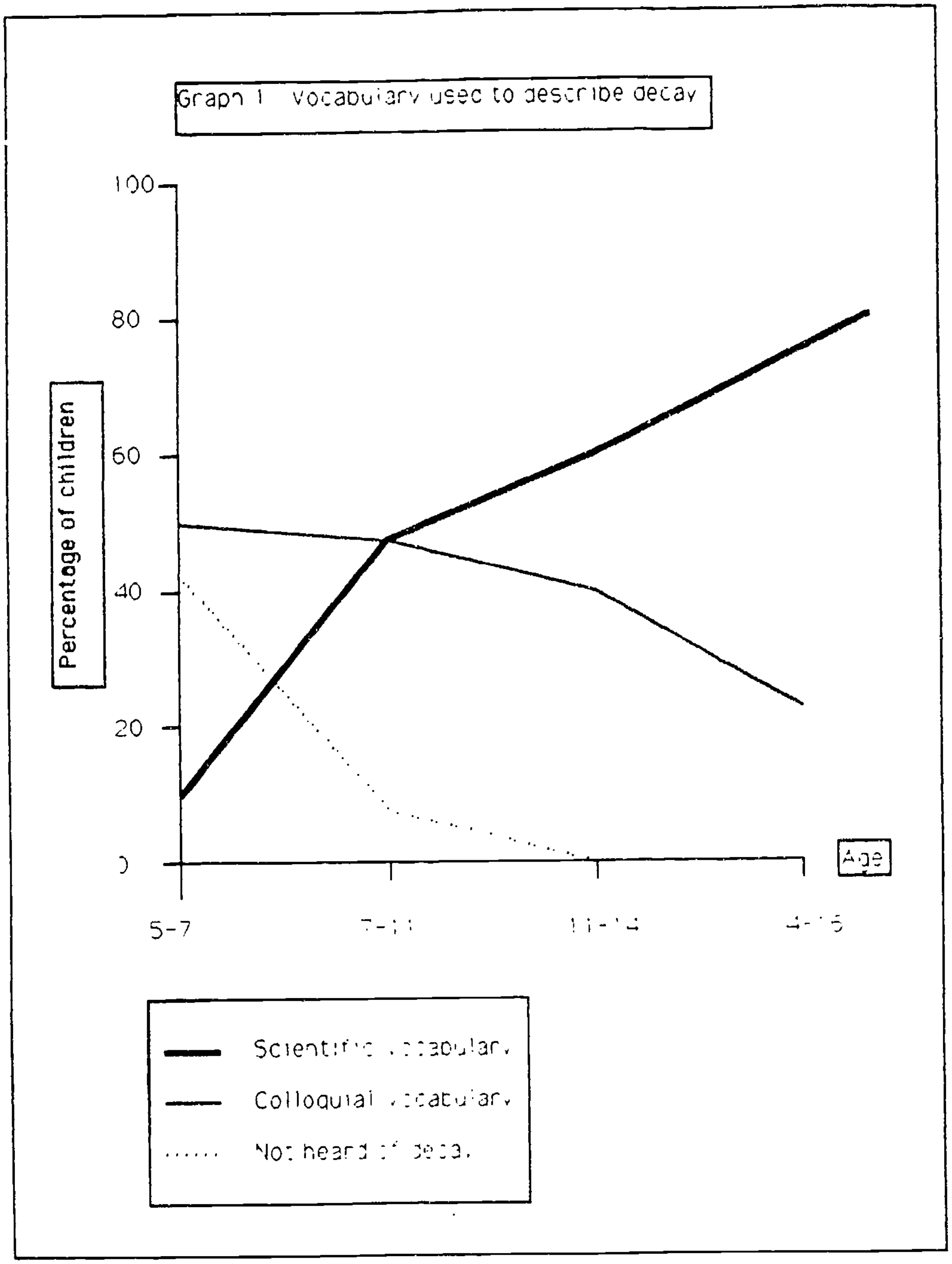
The next section draws on data collected in Massachusetts, focusing on the relationship between children's experience of decay phenomena, their use of language and the ideas used to explain decay phenomena. The final section draws on data collected in Calgary, focusing on the sources of children's ideas about decay.

6.1 Results - The development of explanations from ages 5-16.

There were many more similarities than differences among the findings in all three studies In general, the same ideas were identified to explain decay phenomena in all three countries. though the nature of the populations used in each study make detailed comparison of the frequencies of each idea difficult. For this reason, frequencies from the *Leeds study only* are reported.

6.1.1 Language used by children to describe decay

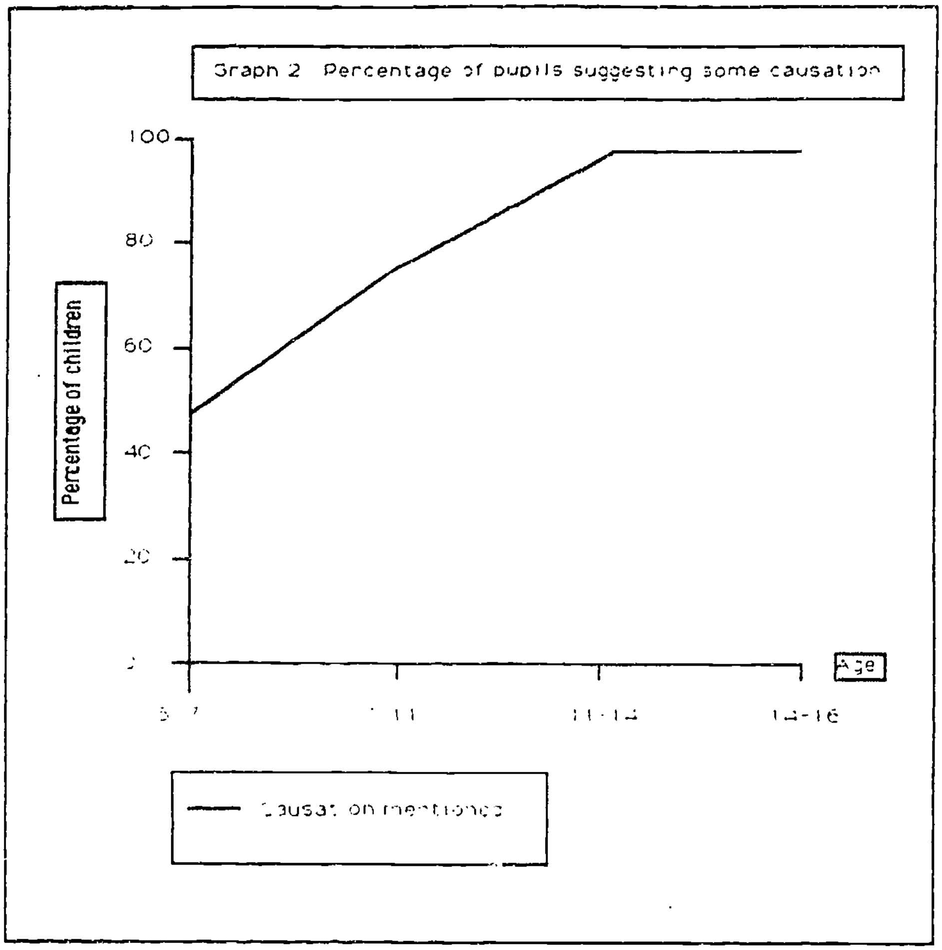
On both the Apple and Video Probes, children were asked to describe their observations of what was happening to the fruit. In describing the decaying apple a change in the language used by children was apparent from age 5 to age 16. Many of the youngest pupils in the sample were unfamiliar with the phenomenon of decay, stating that the bad apple would be good to eat! Graph 1 shows the variation in language used by the pupils on the Apple probe (Leeds study). Words such as 'rotten', 'decaying' and 'decomposing' were classified as 'scientific' whereas words like 'bad' and 'manky' were classified as 'colloquial'. It must be stressed that the use of a scientific word such as 'rotten' or 'decomposing' does not mean that the pupil has a conceptual understanding of rotting or decomposing similar to that of a scientist. Although the numbers differ slightly, the overall progression of the graph slopes were similar to those found in the Amherst and Calgary studies.



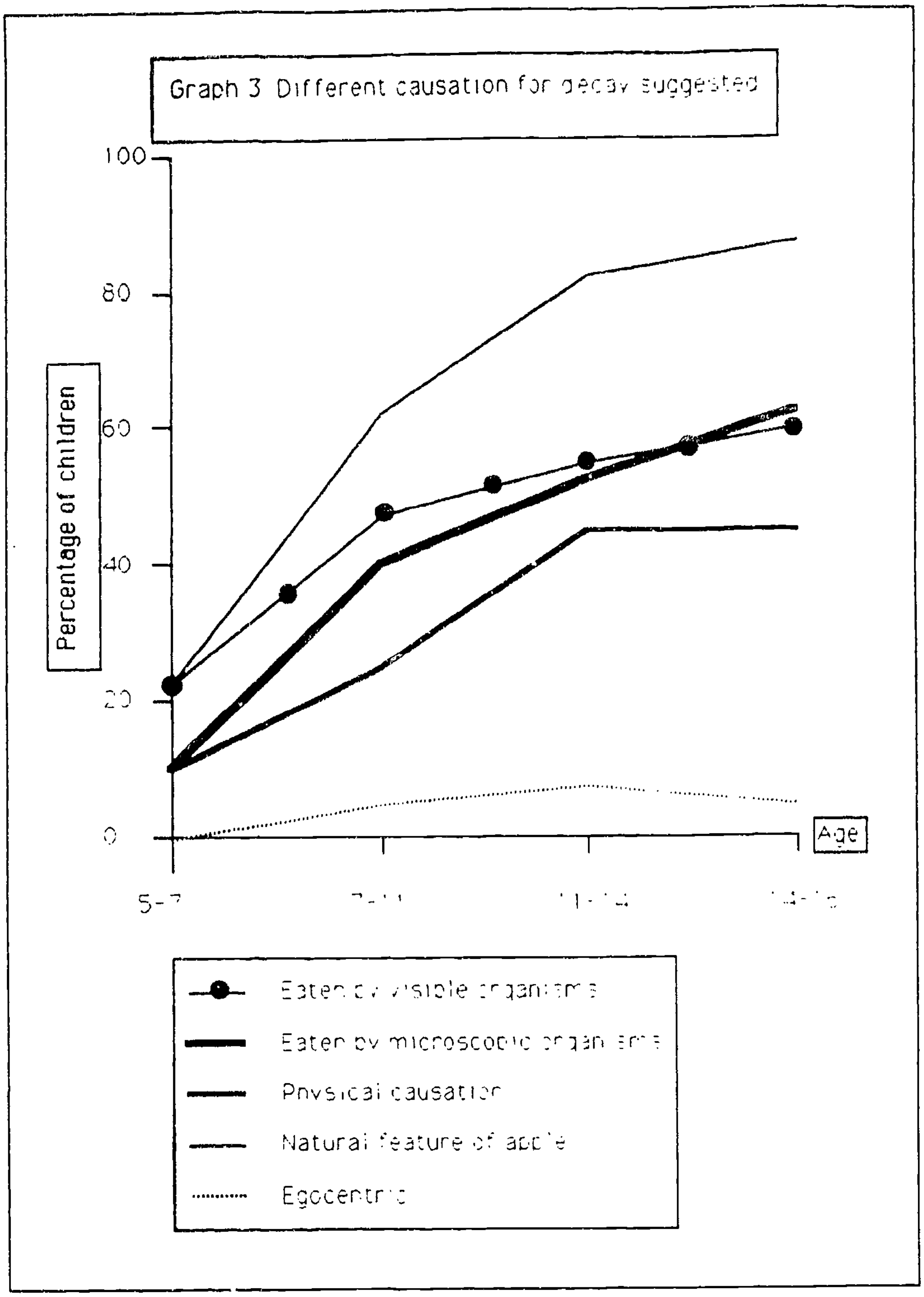
6.1.2 Explanations of the cause of the decay process

After observing the picture of the apple, or watching the video sequence, pupils were asked to comment on what they thought was causing any changes observed. Responses were firstly split into those suggesting one or more causal factors as opposed to those that merely re-stated observations of the process with no mention of causation.

On both the Apple and Video probes there was a marked increase with age in the number of children making suggestions about causation as illustrated in graph 2 (Leeds study):



The explanations offered by children were then further analysed, and five types of responses were identified in the data. Many children referred to the apples being eaten by visible organisms such as insects, bugs and cows; these have been classified as 'Eaten by visible organisms'. Some children referred to the apples being eaten or 'attacked' by micro organisms such as germs, bacteria, microbes and decomposers; these have been classified as 'Eaten by microscopic organisms'. Many children referred to physical factors such as air, sun and heat as being causal to decay; these have been classified as 'Physical causation'. Some of these pupils mentioned the need for the skin of the apple to be broken or bruised. Many of the responses suggested that the children saw decay as a natural feature of apples, so that the reason that apples decay was related to age; these have been classified as 'Natural feature of apple'. This type of response often referred to the tree feeding the apple so that when the apple was removed from the tree decay would result from a lack of food. Many of the responses suggested some sort of egocentrism, whereby apples were seen by the children as a source of food for Human beings rather than as a seed case for apple trees. Decay was therefore related to not being eaten on time. These have been classified as 'Egocentric'. These responses relate closely to the observations of Sequeira and Freitas (1987). Graph 3 shows the frequency of these different responses in the responses of pupils from age 5 to age 16 on the Apple probe.



Explanations offered on the Video Probe were coded into the same categories, and very similar frequencies were observed.

A notable difference in the responses offered by older pupils compared with younger pupils is the number of possible reasons suggested about the causation of decay. Younger pupils tended to suggest just one reason whereas older pupils offered two or more reasons. We were surprised that no pupils, even at the age of 16, related their idea that physical factors such as temperature and moisture affect the process to the role of these factors on microbial and enzymatic action

At the end of the Apple Probe, pupils were presented with a simple description of a germ theory of decay, and asked whether they had heard of this before. Bearing in mind the obvious methodological drawbacks of this approach, a trend could be seen at each age that more children claimed to have heard of the theory than used it in their unprompted responses. The responses of young children about germs tended to suggest that they thought germs were inanimate and associated with dirt, the ground and insects. Several children talked about being told not to eat food dropped on the floor 'because it has germs on it'. It is hardly surprising, then, that 10% of 5 - 7 year olds mentioned germs as possible reasons for decay without prompting.

Data from the Calgary study reflect a similar range of explanatory groups used by pupils at age 7 and age 11

Data collected in Massachusetts showed an increase in the causal use of combination of biological and physical agents through the stages As age increased students seemed more likely to mention both physical and biological causation although they were rarely mentioned as working in tandem but as separate agents acting upon the apple and aiding and abetting the decay process.

Although there was very little mention of complex causal interactions, such as macroscopic interaction breaking the skin to allow the access of microscopic agents, a small number of pupils mentioned the need to break the skin of the apple to allow animals an access to the fruit. This was comparable to responses in Leeds.

6.1.3 Previous experience of the decay process

In the Video Probe pupils were asked whether they had observed anything similar to the process observed on the video at any time before. After the age of 6 very few children claimed that observations of decay were a new experience for them, and progressively more children made links between the decaying fruit on the video sequence and their observations of other decaying foodstuffs in the home or their observations of decaying animals in their immediate environments. Surprisingly few children of any age mentioned composting, given the coverage of this subject in the media at present.

On the contrary, in the US and Canadian sampling, composting was a fairly common experience for most 11-14 year olds (nearly half) and was mentioned by a quarter to a third of the younger students. Gardening or planting of seeds was mentioned by more than half of of the total group. Many children mentioned using a fertiliser of some sort in their planting experiences. Most children could not relate the purpose of the fertilisers beyond the point of explaining that they, 'made the plants grow better', or 'enriched the soil'.

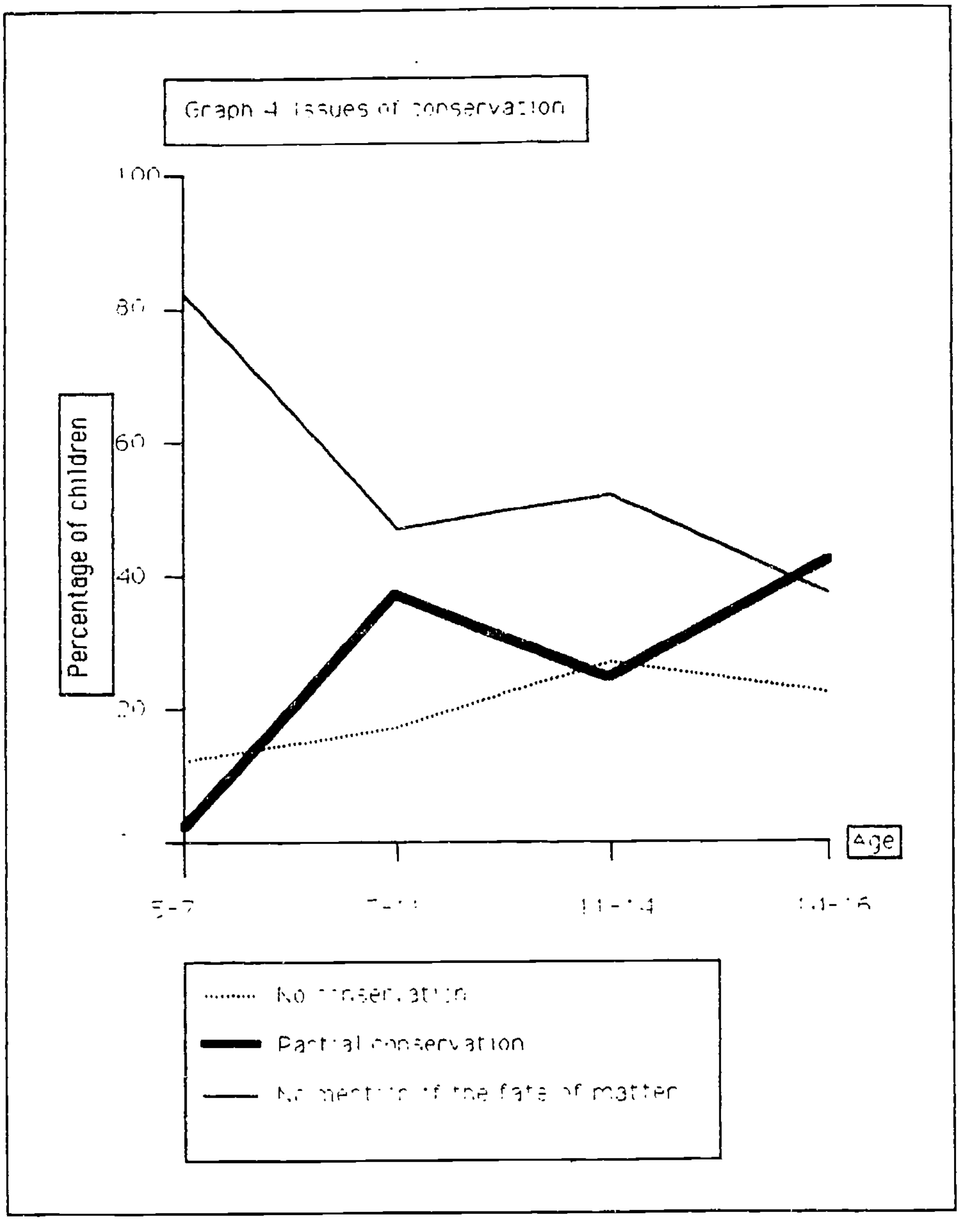
6.1.4 Ideas about matter cycling and conservation of matter

On both the Apple and Video Probes children were asked what they thought would happen over a period of time to the matter from which the fruit was made Interpretation of children's writing on this subject was difficult, as at each age many children did not state directly their ideas about the fate of the matter. Responses such as 'There is less and less' were common. Does this mean that the matter disappears (no conservation), or does it mean that more and more of the matter is transformed and can no longer be seen? Many children suggested that some matter ends up in the soil by some route, though there was evidence that they thought that there would be less matter by this stage in the decay process.

Bearing in mind these caveats, children's written responses were coded into three groups. Many responses were coded as 'Matter not mentioned'. Responses stating that some matter would end up in the environment (usually as part of the soil) were coded as 'Partial conservation', because many responses seemed to suggest that the total amount of matter at the end of the decay process would be less. Responses suggesting that the matter simply disappears were coded as 'No conservation'

Observation of children working on the Video Probe, and interviews with children on the Apple Probe suggested to us that the vast majority of pupils up to the age of 16 did not see any need to explain where *all* the matter goes during the process of decay, and no pupils in the sample showed evidence of relating decay to a comprehensive model of cycling of matter in ecosystems.

Graph 4 shows how responses about issues of conservation were coded for the Apple Probe (Leeds study):



It is interesting to note that progressively more pupils mention the fate of matter with age, and more pupils mention partial cycling through the soil. The observation that more pupils suggest that matter is not conserved can possibly be explained by the fact that the majority of very young pupils do not mention the fate of matter at all in their responses, even when asked specifically.

6.2 The relationship between experience, language use and ideas used to explain decay phenomena

The public awareness of 'green' issues has been exceptionally pervasive during the last few years The media, schools and public organisations have brought this issue to the front in massive campaigns in all communities. There are few communities in N. America which do not have a mandatory recycling programme and combating the 'throw away society' has become a national thrust. Anti-littering laws are universal and children see evidence of these campaigns on TV as well as on the street and in schools. The words of ecology are everywhere. It was the intention of the research team at Massachusetts to find out the extent to which the language and experience associated with green issues affected the conceptual understanding of pupils about decay.

We wondered whether children from rural environments would have a greater understanding of the cycling process due to their greater experience in the natural settings of rural America. Our findings suggest that such students did have more experience, but that experience alone does not result in scientific understanding of the concepts of decay and recycling. Rural students reported substantially more experience with composting than either the suburban or urban subjects. Surprisingly, all groups expressed nearly equal experience with gardens or with 'planting and growing things'. Urban children, however, responded more often than the others that they had learned about these things in school.

A side note of interest should be mentioned here. During the interviewing of several children of Puerto Rican parents, related that their grandmothers put fish (perhaps fishmeal) into the soil to make plants grow better. When asked if they knew why this was done, they responded that they had no idea. Asked if they had ever asked their grandmothers why this process was used, they looked surprised and responded in the negative. This caused us to inquire from cultural diversity experts about the affect and the nature of the response. In that culture, one does not question the action of elders. To ask why, might have been construed as being rude or discourteous. This event should remind us of our need to keep cultural differences in mind in interviewing and in teaching.

6.2.1 Ideas about the cause of decay, matter cycling over time, and conservation of matter

Urban, suburban and rural groups were about equal in mentioning microbes as causal agents except urban 14-16 year olds, where 100% mentioned bacteria. Most of these had learned the terms in biology class. These students' ideas about the cycling of matter, however, were wide-ranging. Several students mentioned the breakdown of tissue into compounds which could be used by the surrounding plants. Students who had finished a Chemistry course seemed to be quite clear about the process even though they had not studied the decomposition of biological material in context. For these students, understanding of the general nature of decomposition of matter seemed to be easily transferred to the problem placed before them. The most complete and thorough explanations in scientific terms were given by students who had substituted a chemistry course for the biology course. Their descriptions tended to be on a more molecular level and the transfer of their chemistry knowledge to the explanation of the biological phenomenon was quite complete and close to the accepted explanation. These were the only students, incidentally, who mentioned the release of matter into the atmosphere during the decay process.

Previous work has suggested that pupils do not tend to conserve matter in chemical change processes involving changes of state (Driver *et al.*, 1985). It seemed to us that many students failed to understand our questioning, reasoning that the matter from the decaying apple could never be re-assembled, and therefore we could never know whether the quantity of matter was the same

Rural students were more likely to express ideas concerning cycling, such as ' the apple rots and provides food for the other plants', than urban or suburban students. They also responded slightly more often that matter would not be lost during the process over time. They had a greater tendency to mention biological agents in causation responses but less often mentioned both biological and physical causation.

Rural children more often referred to macroscopic agents in causation. Perhaps they were more aware of animals running off with rubbish or discarded food because of their surroundings. In truth, a discarded apple will not remain long on the ground: it will be eaten by animals very quickly in most surroundings!

The Leeds, Calgary and Massachusetts studies suggest that knowledge of cycling of compounds through the breakdown of organic material is a rare occurrence in children prior to 15 or 16 years of age. In a few isolated cases, evidence of what we are labelling a concept of 'matter transformation' was found. Even after instruction, students from biology class were prone to talk about the decomposition of the apple by decomposers which enriched the soil and made plants grow better. Just what processes were involved in getting the richness of the soil into the plant were not known. In several cases, students denied the suggestion that compounds from the apple might be incorporated into new plant tissue, in spite of teaching:

> 'I don't believe that! (pause) Although water goes in a cycle...(pause)...but no, not real stuff like apples.'
>
> (Female, age 16, Mass.)

6.2.2 Language used by children to describe decay

Suburban children, not surprisingly, had the highest rate of scientific language used. There was an increase in the use of scientific language through the stages although this is not to be construed that use of words indicated understanding.

6.2.3 Conclusion: experience, language and explanations

Analysis of the data collected in Massachusetts suggests that rural children of a given age are more likely to have direct experience of decay phenomena such as composting. No evidence was found to suggest that this experience resulted in conceptual understanding of the decay phenomena closer to scientific concepts, however. Students who had understood taught concepts to do with chemical conservation seemed able to apply these to biological phenomena without direct teaching.

6.3 Sources of children's ideas about decay

A fortuitous event during the Calgary study provided a surprising finding which prompted much interest among the research team members and the teachers involved in the study. One of the classes (class A) had worked through a unit prior to the showing of the decaying fruit video, developed by their teacher, entitled 'Mould'. The second grade two class (class B) had not worked with the Mould unit, although at one point they were given an opportunity to examine class A's mould garden. The classes were homogeneous in mixture, and were equally balanced in terms of academic ability. Both class A and class B were presented with the videotape and were given an equal opportunity to express their views on the nature of decay and the ultimate disposition of the substances in the fruit bowl. We expected that the children who had the extensive experience with the mould garden would demonstrate more sophisticated explanations and language in describing their ideas. In fact, the opposite was true. Class B, the children who had only briefly glimpsed the mould garden, demonstrated a remarkable superiority in their descriptions of and explanations of the phenomenon. Why?

The search for answers to this question deepened study of the two classes. A comparison of written work was made from the surveys. Interviews were conducted with the children and their teacher and visitations were made during the writing programme. The main difference noted in the explanations were the following: class B as a group demonstrated a view that the mould was 'breaking down' the fruit into smaller and smaller pieces, which then went into the soil and stayed mixed with the soil. Many more students in class B than in class A discussed or referred to composting while describing this process. Students in class A, although also mentioning that the fruit was being broken down, for the most part did not suggest a final physical location for the fruit in its final stages. It was suggested that the fruit then 'went into the air' or 'into nothing'. Class A speculated far less on the ultimate disposition of the materials and did not, as a whole, express the idea of recycling as part of the process.

Interviews with individuals and groups within the class as well as with the teachers of the class suggest that the source of the reasoning for such an unusual finding may be in the very different writing programmes used by the teachers in the two classes. The children in class B participated in a highly expression-oriented daily journal writing experience called 'Writer's Workshop'. The teacher had worked with and developed this programme over a five year period. Through extensive interview and review of the children's written work in both classes, we found that the children in class B more often incorporated their own personal experiences and speculations in their writing and therefore in their thinking about the subject they were writing about. This daily practice apparently transferred to the interview and pencil and paper experience. It appeared to allow the children to draw upon and express their own experiences and speculations more extensively than the children who had conducted the more systematic study of mould. This approach suggests that an approach to writing developed in the science programme may have a very positive effect in encouraging children to express their thoughts, perhaps more freely drawing upon personal, not just school experience. This process may, in fact, help students to learn as they write, by making connections among known and unknown ideas more readily. In any event, findings from the Calgary and Massachusetts studies indicates that experience of phenomena alone is not enough for children to develop scientific explanations of decay.

7 Other Educational Implications

We hope that this research is of interest to any teachers and curriculum planners who are concerned with units involving ecological concepts. The prevalence of explanations of decay phenomena making scant reference to microbial decay and cycling of matter, coupled with the high level of relevant experiences of decay phenomena reported by the majority of students at all levels, should point to the ease with which children adopt the language of ecology and even the politically and environmentally correct actions of ecological concern without needing to use scientific concepts. A reasonable, and hardly surprising conclusion is that participating in an activity alone is not enough to develop conceptual understanding.

In section 7.1 the use of this data in the sequencing of experiences and concepts in the British National Curriculum is described, to illustrate how data on the development of children's ideas can inform curriculum design. Section 7.2 describes one teacher's planning of work on decay and cycling that was informed by a knowledge of her pupils' conceptual starting points. Both sections are intended to illustrate principles that are of wider application that the British National Curriculum. Section 7.3 describes how the classroom environment, and the level of talk in particular, can lead to conceptual development.

7.1 Curriculum Design

The Conceptual Progression in Science Project at the University of Leeds was initiated by the National Curriculum Council, with the aim of informing decisions about curriculum sequencing in biology for pupils from age 5 to age 16. (It should be emphasised that similar research was not commissioned for the majority of conceptual areas of the National Curriculum.) Evidence about the ideas used by pupils to explain phenomena relating to the cycling of matter, flow of energy and interdependency of organisms in ecosystems, and how these ideas develop from age 5 to age 16 was collected. These data were used to inform decisions about sequencing the introduction of concepts in the National Curriculum, setting appropriate assessment objectives for pupils and the nature of National Curriculum assessment objectives themselves.

The National Curriculum for Science (D.E.S., 1989) consists of Programmes of Study, Attainment Targets and Statements of Attainment. The Programme of Study is a list of the science that every child should study from age 5 to 7, 7 to 11, 11 to 14 and 14 to 16. Attainment Targets are lists of assessment objectives (termed Statements of Attainment) in related conceptual areas. Many other science curricula no doubt consist of lists of experiences and concepts for study, and assessment criteria.

Sequencing the introduction of concepts about decay from age 5 to age 16: Writing the Programmes of Study

The Leeds study suggested that at age 5 many pupils were not familiar with the phenomenon of decay, and that many pupils who had witnessed decay did not think of it as a progressive process. By age 7, however, most pupils were familiar with examples of the decay process, though many had little idea about the timescale of the process. It was therefore recommended that the Programme of Study for pupils of 5 to 7 should concentrate on familiarity with decay phenomena, including differences in the rate of decay of different materials.

Between ages 7 and 10 more pupils in the sample mentioned the fate of matter in their descriptions of the decay process, the emphasis being mainly on the enrichment of soil. For this reason, it was recommended that the Programme of Study for such pupils should encourage thinking about the fate of matter in decay in contexts such as composting. (Composting is not as common in the UK as in North America at the time of writing.) In addition, a number of pupils mentioned 'germs', bacteria and fungi in their explanations, but had limited ideas as to what exactly these words meant. For this reason, the introduction of study about decomposing micro-organisms was recommended.

Between the ages of 11 and 14 and 14 and 16 it is hoped that pupils will build an understanding that matter is conserved as a general principle, and that this principle applies to decay. In addition, due to the processes of photosynthesis, feeding, respiration and decay, there is a net cycling of matter in ecosystems. For the vast majority of pupils in the sample, even at age 16, the idea that matter is conserved in contexts involving chemical change from solid to gas was not present. A conceptual change to a view of matter conservation and cycling requires pupils to change key concepts fundamentally, and is consequently demanding. By this age most pupils had some ideas about micro-organisms in the context of decay, with varying degrees of sophistication. Further study of micro-organisms in the context of decay as well as in the more familiar context of disease was therefore recommended.

In addition, no pupils linked their specific knowledge about photosynthesis, feeding, respiration and decay into a concept of a matter cycle. Observation of teaching suggested that this was to some extent due to teaching of each process in isolation with very little mention of the role of the decay process.

For the above reasons it was recommended that the theme of matter cycling should be included in the Programmes of Study for pupils from age 11 to 14, and also 14 to 16. Information for teachers was required to emphasise the difficulty of this concept, and the need for teaching to help pupils to integrate specific knowledge about photosynthesis, respiration and decay.

Setting appropriate assessment objectives for pupils about decay and matter cycling from age 5 to age 16: Revisions to the Statements of Attainment

Statements of Attainment are organised at 10 levels, the attainment of the average 7 year old being level 2, the average 11 year old level 4, the average 14 year old 6, and the average 16 year old level 7.

The National Curriculum for Science (D.E.S., 1989) contained only one Statement of Attainment on decay and cycling relevant to pupils up to age 11, placed at Level 4:

> Understand the key factors in the process of decay (temperature, microbes, compactness, moisture) and how this is important in the re-use of biological material in everyday life.

Data from the Leeds study suggested that although pupils at age 11 were likely to be familiar with the process of decay, it was unlikely that they would have a view of decay and cycling of matter as indicated in the Statement of Attainment. In addition, teachers interviewed seemed to have varying interpretations of the phrase 're-use of biological material in everyday life'. It was recommended that there should be a Statement of Attainment at a lower level relating to familiarity with the process of decay, followed by a statement at around Level 5 about the causes of decay, followed by a higher statement about decay and cycling.

In the National Curriculum Consultation (D.E.S. May 1991) the following series of Statements of Attainment were proposed:

2 Be able to classify waste materials into those which decay naturally, those which can be recycled and those which have to be disposed of by other means

5 Know about the key factors in the process of decay (temperature, microbes, moisture, air).

8 Understand the role of microbes and other living organisms in the processes of decay and the cycling of nutrients.

It was recommended that the statement at Level 2 should relate to decay alone, rather than involving the process of classification. The Statutory Orders for the National Curriculum (D.E.S., 1992) were thus amended accordingly:

> Know that some waste materials decay naturally, and do so over different periods of time.

<u>The nature of National Curriculum assessment objectives themselves (Statements of Attainment)</u>

In analysis of the Statements of Attainment of the National Curriculum in terms of data on the development of children's ideas, it became clear that particular Statements of Attainment were of different status. For example, some required pupils to demonstrate understanding of a concept such as decay whereas others required pupils to apply particular knowledge (such as the management of ecosystems) to a specific context (such as the conservation of North Sea fish stocks). It seemed that assessment in specific contexts was resulting in fragmented teaching in which conceptual learning goals were not always clear. In their consultation (D.E.S., May 1991) the NCC grouped Statements of Attainment into conceptual strands with the following justification:

> 'In combining the statements of attainment into strands, we have been selective in the identification of steps marking a conceptual advance; not every strand is represented by a statement of attainment at every level, although taken together they provide a comprehensive map of progression within the area of the NAT.' (New Attainment Target)

In practice, this meant that Statements of Attainment relating to conceptual understanding could be of more use to teachers in identifying learning goals for students.

7.2 Planning Teaching - Evidence from the Classroom

Science teachers need to be aware of the conceptual starting points of pupils as well as science learning goals, in order to plan to support them on their 'journey of learning'. The nature of the difference between children's ideas and the science learning goals identified can then be considered. At the outset of teaching a new topic, teachers might consider what exactly learners are being asked to do. Are they being asked to develop an existing idea? Are they being asked to make links between a wider number of familiar observations? Are they being asked to change an existing idea for an explanation which is opposed to their initial observations? Are they being asked to learn a new idea, and then use it to explain a number of familiar observations in a different way?

During work in the UK, a programme of teaching entitled "The Environment" was observed with Year 9 pupils (age 13 - 14). Observation was focused on a group of four boys in the class, judged to be of average ability by the class teacher. At the beginning of the topic the teacher used the Apple Probe to find out what pupils thought about the phenomenon of decay; the range of ideas reported earlier in this paper were used by pupils in the class. Having thought about the scientific relationships between photosynthesis, respiration and decay, and talking to various children, the teacher decided that realistic learning goals for pupils relating to cycles of matter would be:

-decay is important in cycling matter, both *via* the soil and *via* the atmosphere.

-microbial action is important in decay.

In addition she hoped that some pupils would be able to make links between photosynthesis, respiration and decay in their thinking about matter cycles. This was emphasised during teaching.

The teacher did not anticipate many problems for pupils in moving from their prior ideas about the cause of decay to a view involving microbial action; she knew that many children had heard of microbes from their writing on the part of the Apple Probe where a germ theory of decay is presented. By contrast, moving from an idea that matter can 'disappear' during decay to a view that matter is conserved and cycled in communities would involve a complete change of viewpoint for pupils.

Before instruction, all four pupils being observed mentioned factors such as temperature and being eaten by insects as causing decay. At the end of the period of instruction all four pupils mentioned microbial action along with other factors. The teacher had rightly predicted that this part of the curriculum would not pose problems for the pupils.

Teaching about matter cycling was spread over two lessons of seventy minutes each. During the first lesson, pupils observed the extract of videotape used in the Video Probe, and worked in groups of four to provide answers to the focus questions. During the second lesson, the class teacher took feedback from each group of pupils about their explanations for the decay process. She then presented 'a scientific view' of what happens in decay to the class.

The four pupils under observation had agreed that the amount of substance decreases during the decay process in their groupwork. The explanation of the class teacher focused on the conservation of matter in decay. At the end of this lesson the four pupils were interviewed about this apparent mismatch between their ideas and the ideas of their teacher:

Interviewer	*You know we were talking about stuff getting smaller yesterday - you saw it on the video - why do you think the stuff was going to get smaller?*
Pupil 1	*It were all eaten inside...*
Interviewer	*What ate it?*
Pupil 1	*The maggots and decomposers.*
Interviewer	*I see, and at the end of the video. I know this is impossible, but just supposing, if we could collect together all the stuff that hadn't been eaten, and the stuff that had, and get it all back together do you think it would have the same amount of stuff there?*
Pupil 2	*No! A bit of it'd have disintegrated.*
Interviewer	*Just gone all together?*
Pupil 2	*Yeah.*

The word 'disintegrated' was consistently used by the pupils to indicate a disappearance with a reduction in mass. During the interview one pupil suggested that the only way to resolve the dichotomy between their ideas and the ideas of their teacher was to perform an investigation. A design was agreed upon in which an apple was chopped up and placed in a sealed glass jar. The jar was weighed over a period of three months, and a record was kept of the state of decay of the apple. At the start of the investigation, three of the four pupils predicted that the mass would decrease as decay progressed; the one pupil stating that the mass would remain constant justified this claim by stating that no decay would occur in a sealed jar because no microbes would be present. If decay did occur, then the mass would decrease.

In fact, the mass of the jar decreased by 0.7g over the three months. Both the class teacher and the researcher were surprised at the maintained interest of the pupils in their investigation over this time period. At the end of the investigation the group of pupils were interviewed about their conclusions. All the pupils thought that the change of 0.7g was significant and indicated that some of the apple had 'disintegrated'. Sections of the transcript of this interview are shown:

Interviewer	*OK, I have several questions I'd like to ask you. I was very interested in the discussion we had about your apple last week. When we set this up you made a prediction. M***, you said that you thought it'd get lighter, D***, you thought it'd stay the same, D**** said lighter and G**** also said lighter. Someone's written in there, I don't know whose writing it is, that no microbes will be getting it - because it was sealed?*
Pupil 1	*Oh yeah..*
Interviewer	*So that's why you thought it'd be the same, D***?*
Pupil 1	*Yeah, but G**** knocked it so it wasn't the same. (...) The lid came off.*
Interviewer	*So something might have got out. When we spoke you said that there was a smell, which suggested that something had come out. Looking back at the results, on the tenth of October it was 397.5g and by the end, last week, it was 396.8g.*
Pupil 2	*It's gone down.*
Interviewer	*It's gone down by how much, would you say?*
Pupil 2	*Two grams.*
Interviewer	*No...less than a gram. By 0.7 grams, less than a gram. OK..(...)Why might it have got lighter?*
Pupil 2	*The gases'd have got out.*

It seemed apparent to the interviewer that the pupils had a clear understanding about the variables relevant to making this investigation a 'fair test'; if something escapes from the jar then the mass will decrease. This decrease cannot, however, be used as evidence that some of the apple has 'disintegrated'. The interviewer then went on to find out how the pupils explained the decrease in mass of 0.7g:

Interviewer	*If G**** hadn't knocked it over do you think that it'd have stayed the same?*
Pupil 3	*No, cos all the stuff, all the juice...*
Pupil 2	*Even after G**** knocked it, you could smell all the stuff coming out, couldn't you, M****? It smelled cider-ish..*
Pupil 1	*It disintegrates...*
Interviewer	*What I'd like to ask you is this. You predicted, when you set the thing up, that it was going to get lighter, and D*** said the same. Do you still think it would have been the same, if you'd kept it sealed?*

(...)

Interviewer	*How about you three, then, M***, how about you. Do you think it'd have got lighter even if he'd not knocked it over.*
Pupil 3	*Yeah, probably, yeah.*
Interviewer	*Right, a point leading on from that then, why do you think it might have got lighter?*
Pupil 2	*Because, the chunky stuff, it might have...juice is lighter.*
Pupil 3	*it could have disintegrated.*
Interviewer	*And if it disintegrated it would have got lighter?*

Pupil 3 *Yeah.*

The pupils seemed to have three possible reasons for the decrease in mass in mind. Firstly, some of the 'stuff' in the jar could have escaped. Secondly, the pupils thought that liquids tend to be heavier than solids (in common with the findings of Driver *et al.*, 1985), and thirdly, some of the matter could have 'disintegrated'. The pupils seemed convinced that part of the decrease in mass was due to matter from the apple 'disintegrating' during the decay process.

What can we learn about children's learning from this example? Firstly, the teacher correctly predicted from the responses of pupils prior to teaching that certain aspects of "The Environment" module would pose more problems for her pupils than others. This may sound trite, though in discussions between the class teacher and the interviewer at the beginning of the module the class teacher expressed surprise that the children did not remember more about microbes from previous teaching, and amazement that so many children thought that matter could vanish during the decay process.

The children's investigative work was guided by a genuine interest on their part to find answers to their own questions. It was carried out with care and commitment by the pupils. Their interpretation of the data, however, was guided by their existing idea that mass is not conserved during decay, and this idea was confirmed rather than refuted by their investigative work. For these pupils the idea that mass decreases as the fruit appears to get smaller is obvious; it is the science idea that mass is conserved which defies belief!

Many teachers may be sceptical of our results, and assume that *their* pupils would not answer in the same way. We urge such teachers to try these tasks with their classes, as teachers with whom we have worked have all found the experience of talking in depth to pupils about their explanations for scientific phenomena illuminating.

It seems that open-ended investigative work of this nature may not be the best strategy for promoting conceptual change in areas where achievement in the science curriculum requires learners to undergo some sort of 'radical restructuring' (Carey, 1985) of their ideas, moving away from the perceptually obvious aspects of phenomena to more abstract ideas in their explanations. Stavy (1991) has described teaching about the conservation of matter starting with experiences of conservation of matter that have strong perceptual appeal for students (sublimation of iodine). This was followed by less obvious examples (evaporation of acetone). It was found that performance on the acetone task was significantly higher when it followed the iodine task.

7.3 Classroom environment: talk and conceptual change

In the process of determining students' ideas about the nature of decay, several opportunities were provided by the researchers to encourage students to display their current understandings by talking or writing about phenomena presented to them. In the course of this work, as noted in the unusual situation in the Calgary study, researchers were reminded that ideas are often made clear, not only to the researcher in this process, but may emerge for the first time to the subjects themselves in the act of speaking or writing. That is, speaking or writing about ideas often allows us to put together the familiar and the unfamiliar in new ways. The children's ability to speculate about ideas about decay and the ultimate disposition of matter were clearly related to the expressive abilities of students in the study, in particular during the writing programme. In addition to important implications for research, in the interviewing of students, this suggests that teaching approaches which enhance students' opportunities to express ideas freely on an ongoing basis will allow them to demonstrate their thinking and patterns in thinking to teachers who can become researchers of student thought in their own classrooms. Ultimately, students become clearer about their own thoughts and thought processes.

8 The research perspective - a postscript

In section 7, data are presented to illustrate that factors related to both science concepts and the learning environment designed to promote conceptual change affect learning. For example, the pupils who conducted an investigation into the conservation of mass in decay did not change their initial notion that mass would *not* be conserved throughout a sequence of instruction; it seems that the conceptual change required to move from a view that matter appears and disappears in decay to the view that in closed systems the total amount of matter (and therefore the total mass) remains constant was too large a barrier for this sequence of instruction to overcome. A radical constructivist perspective, in which learning is seen as conceptual change of ontologically basic concepts such as 'mass' or 'matter' seems useful to interpret this teaching (Carey, 1985; von Glasersfeld, 1989). In addition, the fact that pupils in the differing environments described in the study used such similar explanations of decay suggests a model of learning in which the individual response to the phenomenon takes prominence over more affective factors. Cross-cultural studies in other domains have yielded similar patterns in the explanations offered (e.g. Mali and Howe, 1979).

Data were also discussed in which the most important factor in learning seemed to be the culture of language usage in the classroom. In the classroom in which the culture was to use language creatively and expressively, learners seemed better able to focus their explanations of decay on a range of facets of the phenomenon that learners of similar ability who had had more experience of the decay phenomenon, but without the benefit of the creative writing programme. A social constructionist perspective seems most useful to interpret this teaching (e.g. Lemke, 1990); a radical constructivist perspective seems to suggest that the pupils with greater experience of the phenomenon of decay would be best able to explain the process.

We are concerned that there is no epistemological perspective in the science education literature through which we can adequately interpret our data, though recent work in mathematics education has started to bring together social and personal constructivist perspectives (Wood *et al.*, 1991). On the one hand, perspectives associated with a radical constructivist epistemology place emphasis on learning as conceptual change to empower the learner to explain phenomena, with little reference to the role of the community in which learning takes place; on the other hand perspectives associated with a social constructivist epistemology place emphasis on the role of the community in which learning takes place, but pay little attention to conceptual problems associated with the subject matter, and do not seem to explain cross-cultural similarities in the explanations offered by learners in a number of scientific domains.

We urge epistemologists working in science education to address this issue.

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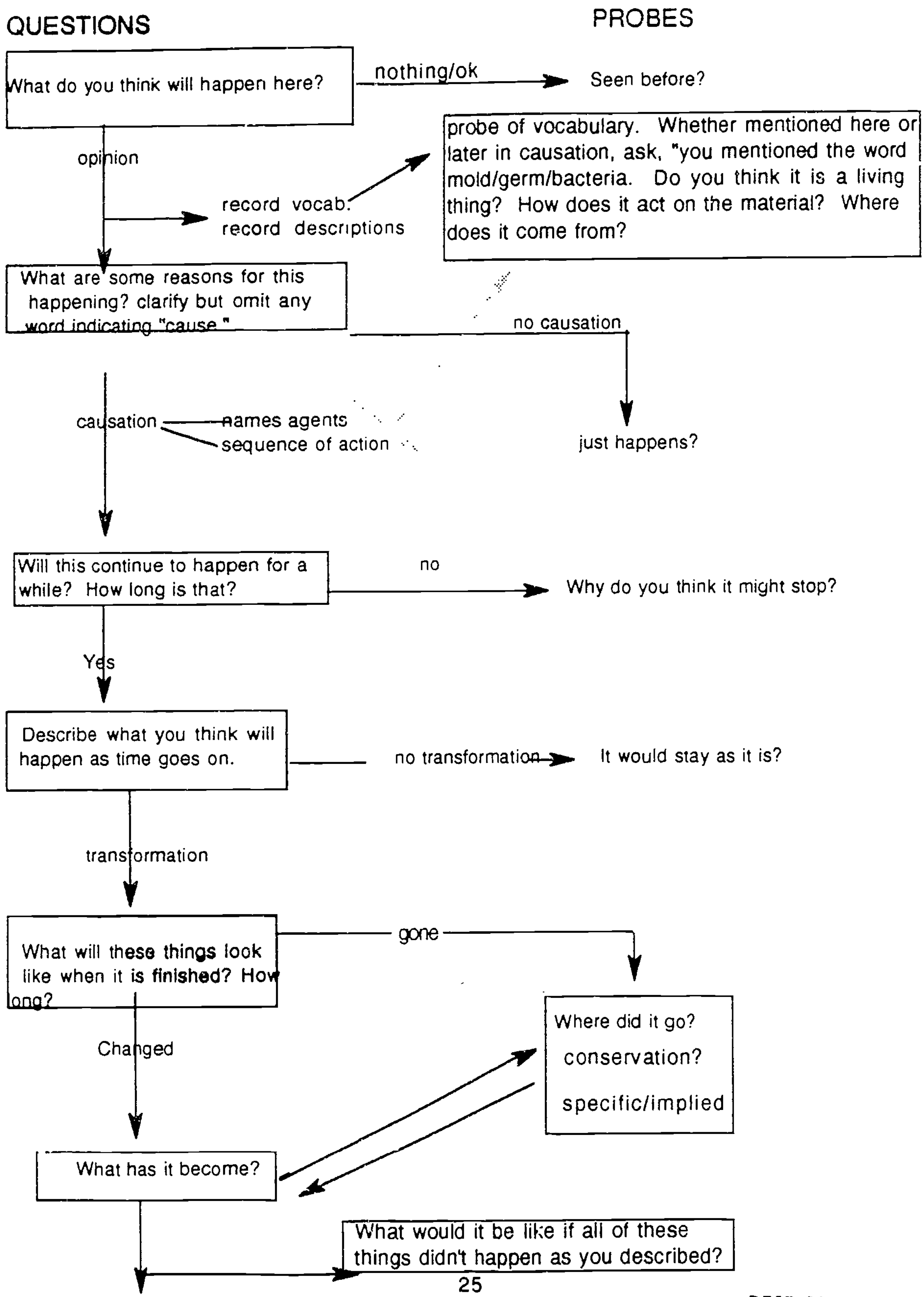
Appendix

Massachusetts Interview Protocol



VIDEO

Name: .... Age: ....

Date: .... School: ....

* What do you think is happening to the fruit?

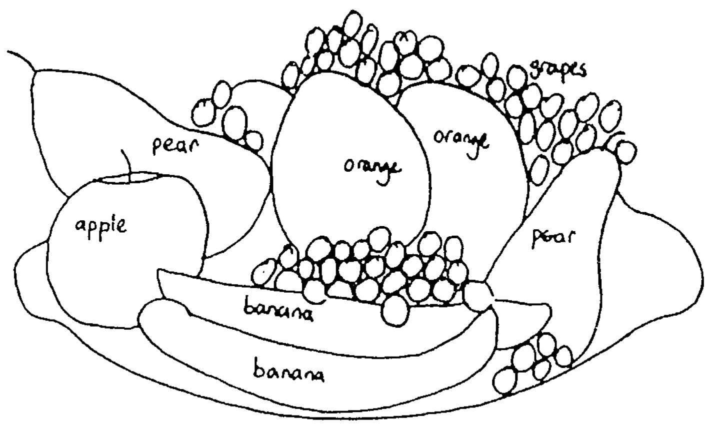
___

___

___

___

* Show as best you can on the drawing what happens to the fruit. Label the parts you add to the drawing:



* If the video were shown at normal speed (not time lapse) how long do you think the whole process would take?

___

* Have you seen anything like this happening to fruit before?

.... Yes .... No

Where did you see it? ___

___

___

* Have you seen anything like this happening to anything else before?

.... Yes .... No

Where did you see it? ___

___

___

* What happens when you throw the fruit in the bin? Where does it go?

___

___

___

Then what happens to it?

___

___

___

What happens next?

___

___

___

Anything else?

___

___

___

APPLE

Name: .... Age: ....

Date: .... School: ....

This is an apple tree, in Autumn. The wind has blown some apples off the tree, on to the ground below. Here is an apple that blew off the tree a couple of weeks ago.

* What do you notice about the apple?

____

____

____

* What do you think is making this happen? Write down what you think!

____

____

____

* Do you think that anything might happen to the other apples, left on the ground? Write down what you think!

____

____

____

* If nobody touches these apples after a whole year, what might happen? Write down what you think! Where might the 'stuff' that the apple is made of go to?

____

____

____

APPLE

Name. .... Age. ....

Date: .... School: ....

* Scientists believe that some very tiny living things called microbes do this to the apple. Some people call these microbes "germs". Moulds are a type of microbe, too. Have you heard of this idea before?

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* Write down anything that you think that you know about this idea!

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