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Children's ideas about micro-organisms: a cross-age study

by

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Abstract

This research explored children's ideas about micro-organisms across three age groups and employed a survey methodology using multiple methods. The research focussed on exploring children's ideas across specific conceptual themes pertinent to understanding about micro-organisms.

Data were analysed qualitatively and quantitatively and a hierarchy of mental models for each conceptual theme, typical of children's ideas across all the age groups, was developed as a result of data analysis. What this research has established is that the prevalence of the different models for each conceptual theme alters between different age groups. A typology of these models for each age group has been developed and this has shown how children's ideas change with age, what levels of progression occur and in which particular conceptual themes progression is greatest.

Two important themes emerged from the data; these were anthropocentric ideas and an associated notion that micro-organisms are essentially malevolent. These themes were evident in children's ideas across all age groups and throughout the conceptual catalogue being investigated. A negative view of micro-organisms dominates many children's thinking in such diverse concepts such as classification, living, disease and decay.

In light of the findings implications for learning and teaching microbiology at school, for the age groups studied, are discussed and implications for curriculum development are considered. Recommendations for further research are also discussed.

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Abbreviations and Explanations

CLIS	Children's Learning in Science Project
DfEE	Department for Education and Employment
DfES	Department for Education and Skills
DNA	Deoxyribose Nucleic Acid
LEA	Local Education Authority now known as Local Authority (LA)
Ofsted	Office for Standards in Education
QCA	Qualifications and Curriculum Authority
RNA	Ribose Nucleic Acid
SPACE	Science Processes and Concepts Exploration Project

Chapter 1

Introduction and rationale for the research

1.1 Introduction

The reasons for conducting this research project, which investigates children's ideas about micro-organisms are, that it is of value to me, as a researcher in science education and that it will hopefully have relevance for the wider research and education communities. Dawson (2002) suggests that asking the 'why' question is an important question to consider before embarking on any research project. This arises because the motives for doing the research in the first place will affect the selection of the topic, how the research is conducted and how the results are reported. Exploring the reasons for the research will help to ensure that a clear focus and sense of purpose for the project is elicited from the outset. There are three interrelated reasons for carrying out this research:

- Curricular and pedagogical;
- Scientific;
- Personal and professional.

1.1.1 Curricular and pedagogical reasons

Many statutory curricula include work about micro-organisms. In England, it has been a statutory requirement since the introduction of The National Curriculum that children in Key Stages 2 and 3 (ages 7-14) are taught about micro-organisms, Department for Education and Employment/ Qualifications and Curriculum Authority (DfEE/QCA, 1989). However the teaching and learning that appears to take place tends to be fairly perfunctory and certainly less practical than it might be. Lock (1996:65) noted a significant decline in the amount of practical work undertaken in secondary schools between the 1960's and 1990's with the most severe decline occurring within microbiology, *'pitifully few of these experiences would be with microbes'.* Changes to curriculum content and possibly over-zealous concerns about health and safety would seem to be key factors in these changes. As a result, the work often focuses on children's research about good and bad micro-organisms resulting in a poster for the classroom wall. If practical work is undertaken it tends to be a study of the effects of decay on an apple or something similar.

The research undertaken in this study will add to the body of knowledge about children's ideas in an area of science which is not thoroughly investigated and should lead to a greater understanding of what children think and understand about micro-organisms from age 7 to 14 years. In doing so, the research may help to indicate how the science curriculum could be adapted to teach microbiology appropriately for all age groups and indicate ways of improving what happens in classrooms during lessons on microbiology.

1.1.2. Scientific reasons

Micro-organisms are central to life on Earth. Life could not exist without them and humans have exploited many microbial activities for their own benefit. Micro-organisms and their activities are also becoming increasingly utilised in fields as diverse as medicine, mining and ecology. In contrast to these useful and beneficial microbial activities, their non-beneficial effects are frequently highlighted in the news and media, under emotive headlines, for example; *'Killer Germs',* in *The Guardian* (Meek, 2001) and *'Killer Jet Bug',* in *The Mirror* (Fisher, 2003). They are often presented in such a spectacular and controversial manner that the reader or listener may take away the impression that all micro-organisms are dangerous or even deadly. In a climate where scientific literacy and the public understanding of science is becoming increasingly important (Millar, 1996; Millar and Osborne, 1998; Reiss, 2002), it seems imperative that children should be well informed about these aspects of science, including any ethical and social dimensions, and how they may impact upon their everyday lives. This is particularly pertinent with regard to micro-organisms and their increasing use in medicine, food production, environmental protection and other aspects of biotechnology (Lock and Miles, 1993; Lock *et al.*, 1995; Hill *et al.*, 2000; Simonneaux, 2002; Dawson 2003).

The research presented here will help to further our understanding of how the interest in, and knowledge of, micro-organisms could be developed and improved during children's schooling. This may help to enable children to have an understanding of the issues pertaining to microbial applications, and may increase the enthusiasm of some pupils so that they are encouraged to further their study and become the microbiologists of the future.

1.1.3 Personal and professional reasons

I have a personal academic interest in microbiology as this was the subject of my first degree. The subject is a very important one and it should have a higher profile within the science curriculum for all key stages. However, during visits to schools, in my capacity as a lecturer in initial teacher training, I have been aware that no specific work about micro-organisms is done at Key Stage 1 (ages 5-7) other than considering hygiene rules; little microbiology is taught at Key Stage 2 (ages 7-11) or even at Key Stage 3 (ages 11-14). The research findings may help to encourage more teachers to become engaged with microbiology and develop an enthusiasm for such a fascinating subject which they can pass on to their pupils.

In addition to the paucity of work done in schools, children's ideas about micro-organisms are relatively under-represented in the research literature, even when compared to other areas of biology, and the research that has been undertaken does not extend to any recent U.K. studies. Within the literature that does exist, little is known about the way in which children's ideas about micro-organisms develop and change with age and maturity, or from direct learning, as a result of covering National Curriculum requirements. As a science educator, I would like to be able to offer more insightful research-based evidence about the way children learn specific scientific ideas and concepts, as well as, how those ideas develop with age. This study should help in this endeavour.

1.2 Research questions

The opportunity to reflect upon and articulate the reasons for doing this research has helped to inform the research design and in particular the research questions that will direct the research.

Verma and Mallick (1999) assert that research questions or hypotheses are needed to define what is to be investigated in order to prevent the investigation becoming too broad in scope or disorderly in research design. As van Dalen (1966:457) states, *'no scientific undertaking can proceed effectively without well-conceived hypotheses.... without hypotheses, research is unfocussed, haphazard and accidental'.* Research questions, therefore, provide the researcher with specific foci that are encompassed within the general aim of the research project and help to shape the consequent research design and methodology.

The research presented here considers children's ideas about micro-organisms. Research into children's ideas in science education is now very well established (e.g. Osborne and Freyberg, 1985; Driver *et al.,* 1994), and a great deal of work has been conducted about how children conceptualize different biological phenomena; for example, growth (Russell and Watt, 1990); life processes (Osborne *et al.*,1992) and ecology (Leach *et al.*,1992, 1996). However, less research has been devoted to discovering children's ideas pertaining to micro-organisms. Furthermore there still remain questions about how children's ideas change with maturity. The aim of this research is to discover what ideas and conceptual understanding children have about micro-organisms at different stages of their school career. The four key questions presented below focussed the research and provided strategic direction:

1. Can children's ideas about micro-organisms at different ages be identified, described and quantified?
2. Can changes in how micro-organisms are conceptualized at different ages be identified, described and quantified?
3. Can coherent mental models be constructed that are representative of children's ideas about micro-organisms?
4. Can a typology be developed to illustrate progression of children's ideas about micro-organisms?

In answering these questions, particular dimensions of research are fulfilled. The research provides empirical data, which enables reflection and new thinking about the way in which children's ideas change and develop with age and maturity. It therefore adds to an established body of knowledge and it is innovative in developing recommendations for curriculum development in micro-biology.

1.3 The research project

This study, a cross-age survey employing multiple methods, is timely. It will begin to redress the balance of research in this area of biological science education by expanding and developing what is already known about children's ideas of micro-organisms, as well as how their ideas develop and change with age and maturity. The resulting information can then be used to consider how to address issues of curriculum development in this field of biology. The cross-age study described here is unique within this field of biology and presents an original perspective on the development of children's ideas about micro-organisms. Furthermore, the research employs a novel technique to elicit children's ideas about micro-organisms.

The work that follows contains the details of the research and is organised as outlined below:

Chapter 2:	Review of the existing literature of children's ideas about micro-organisms;
Chapter 3:	The theoretical framework, the research paradigm, methodology, design of the main study;
Chapter 4:	The pilot study, the research methods used in the main study, issues of validity and reliability and details of data analysis;
Chapter 5:	Findings from the main study;
Chapter 6:	Discussion of the findings including the development of mental models and typologies, implications for learning, teaching and curriculum development, limitations of the study and recommendations for future work, concluding comments.

Chapter 2

Literature review

2.1 Introduction

The importance of micro-organisms and microbial activity should not be underestimated in school science (Williams and Gillen, 1991; Gillen and Williams, 1993; Lock, 1996; Schaechter *et al.* 2004). Children should know about the vital role micro-organisms perform within medicine and health, ecology and environmental protection, food production and biotechnology in order to understand and appreciate the importance of these aspects of science in their everyday lives. As technologies involving micro-organisms develop, it is increasingly necessary for children to be aware of the effects that these aspects of science can have and the ethical and social issues they raise (Lock and Miles, 1993; Lock *et al.*, 1995; Lock, 1996; Fullick and Ratcliffe, 1996; Hill *et al.*, 2000; Rota and Izquierdo, 2003; Schaechter *et al.*, 2004; Byrne and Sharp, 2006).

From an educational point of view, and in recognition of their importance, micro-organisms are included in the science curricula and curriculum guidelines of many countries around the world. In England, for example, it has been a statutory requirement to teach about micro-organisms since the introduction of the National Curriculum for science in 1989 (DfEE/QCA, 1989). Nevertheless, curriculum content for microbiology is minimal up to the end of Key Stage 3 (ages 11-14). This could have a negative impact on children's understanding of micro-organisms and could affect later learning (Osborne and Freyberg, 1985). Despite this, there is scope to teach about micro-organisms, because the National Curriculum encourages teaching, 'the big pictures', and science narrative (DfES/QCA, 1999). Furthermore, it is essential to educate children to be scientifically literate if they are to make informed decisions about science-related issues (Millar and Osborne, 1998; Harms, 2002; Simonneaux, 2002; Osborne *et al.*, 2003; Ratcliffe and Grace, 2003), and this would include consideration of microbiology and the growth in technologies involving micro-organisms. Children's ideas about micro-organisms, explored in this study, include what they have learnt in the school curriculum. A more comprehensive account of curriculum requirements and schemes of work about micro-organisms is presented in Chapter 3.

This chapter provides a review of the literature with regard to children's ideas about micro-organisms and connects this study with the body of research about children's ideas in science. An account of the scientifically accepted view of micro-organisms follows and this provides a framework of reference within which to locate the ideas children have about micro-organisms in this study, and those found in the literature. Finally, an overview of the issues with regard to language and children's learning in science is provided.

2.2 Children's ideas about micro-organisms

The field of research about children's ideas in science education, is well-established (Children's Learning in Science (CLIS), 1984-1992; Driver *et al.*, 1994; Osborne and Freyberg, 1985; Science Process and Concept Exploration (SPACE) 1990-1998). Studies such as those referred to, and the one presented here, are based upon the constructivist view of learning, which is discussed in Chapter 3. The constructivist view of learning has informed researchers and practitioners about how children view the natural world and has been influential in developing perspectives about how children learn science. However, children's ideas about micro-organisms are under-represented, in comparison to the wealth of information available in some other areas of biology, in the research literature. Despite this, some valuable work in this area has been published by Nagy (1953); Maxted (1984); Vasquez (1985); Prout (1985); Bazile (1994); Leach *et al.* (1996); Kalish (1996a; 1996b; 1997); Au and Romo (1996, 1999); Simonneaux (2000) and Inagaki and Hatano (1993; 2002). However, little recent work has been conducted on primary aged pupils; for example, Nagy's work on the representation of 'germs' by British children aged between eight and eleven years old and American children between five and seven years old was conducted over fifty years ago. Other studies have tended to concentrate on the ideas and knowledge of older students and pupils (Maxted, 1984; Vasquez, 1985; Bazile, 1994; Rene and Guilbert, 1994; Simonneaux, 2000). In addition, the methods, aims, number of respondents and the terminology used in each study are varied. These variations provide fertile ground for further work to deepen our knowledge of children's ideas about micro-organisms and how these change with age. That said, within the research that does exist, several key themes have predominated and it is intended that these form the basis of the review of the literature for this study, as indicated below.

The themes included in this chapter are children's ideas about micro-organisms in relation to:

- 2.3 classification;
- 2.4 morphology;
- 2.5 the living and non-living state;
- 2.6 size and scale;
- 2.7 disease, health and infection control;
- 2.8 ecology and ecosystems;
- 2.9 technological applications.

2.3 Classification

Grouping and classifying are part of the child's 'natural' psychological development in ordering and making sense of their world (Inhelder and Piaget, 1964). The classification of living organisms and the basic concepts of 'animal' or 'plant' are fundamental to biological theory and the life sciences. The development of these ideas by children is important, as they can provide precursors to more sophisticated concepts such as morphology, physiology, inter-dependency and genetics. It has been shown that young children are able to sort, classify and categorise especially if the attribute of shape is involved (Braund, 1998; Shepardson, 2002). It might seem that an ability to classify everyday and common living organisms into broad categories of plant and animal would not be a difficult task, or indeed a task that could not be successfully undertaken by young children during infant schooling. However there is much evidence (e.g. Ryman, 1974a; Ryman, 1974b; Trowbridge and Mintzes, 1985; Osborne and Freyberg, 1985; Braund, 1991; Tunnicliffe and Reiss, 1999; 2000; Tunnicliffe, 2001) to suggest that this is not the case and children do have difficulty in recognizing different plants as plants and animals as animals (Bell, 1981; Bell and Barker, 1982; Barker, 1995; Jewell, 2002). Even at later stages of schooling, children seem to rely upon physical characteristics such as size and shape to determine the organism presented to them. This limited concept of animal and plant is likely to influence the way in which children categorize micro-organisms for several reasons:

- the terminology, for example, bugs in reference to micro-organisms, can be used to mean other living organisms;
- children are unlikely to have any direct experience of observing micro-organisms other than perhaps mould and mildew on organic matter such as rotting fruit or bread;
- children are more likely to employ previous mental models rather than information gained at school in order to classify micro-organisms.

Maxted (1984) found that some children she interviewed used the terms 'bacteria' and 'germs' interchangeably, whilst some children considered that the term 'germs' was generic and included bacteria and viruses. The term 'bug' was also employed by one child. Prout (1985) discovered, in his study of fifty-four 15-year-olds, 78% were aware that the common cold was caused by some kind of germ, but only 9% knew that bacteria and viruses were different kinds of organisms. Similarly, Simonneaux (2000) found that the terms 'bacteria' and 'viruses' were used interchangeably; whilst one student thought that bacteria were a group of micro-organisms stuck together. Others in the same study considered germs and bacteria to be different; for example, some thought that germs are elements of bacteria or dust and are inert, only when they have regrouped into bacteria (or viruses) could they become active and grow in order to begin to infect an organism and cause illness. Germs (Nagy, 1953) and micro-organisms (Simonneaux, 2000) were also classified as 'things' not being ascribed to an animal (or plant) category at all, but more akin to inanimate objects such as dust, poison, dirt and so on.

Ever since van Leeuwenhoek first saw bacteria under his microscope there has been the notion that micro-organisms are more akin to animals than plants; he described what he saw as *'wee animalcules'*, and noted that they moved around. He considered them to be an animal-like life form, as this extract from his letter in *Philosophical Transactions* indicates:

> "I then most always saw, with great wonder, that in the said matter there were many very little living animalcules, very prettily a-moving. The biggest sort. . . had a very strong and swift motion, and shot through the water (or spittle) like a pike does through the water. The second sort. . . oft-times spun round like a top. . . and these were far more in number. An unbelievably great company of living animalcules, a-swimming more nimbly than any I had ever seen up to this time. The biggest sort. . . bent their body into curves in going forwards. . . Moreover, the other animalcules were in such enormous numbers, that all the water. . . seemed to be alive."
> (van Leeuwenhoek, 1700-1701: 635-642).

Conceptualising micro-organisms as small animals is still prevalent. Much of the current research described in the following paragraphs, indicates that children consider bacteria and viruses to be like little animals, or to have animal-like characteristics, whereas fungi are categorized more frequently as plant-like but are not considered to be plants or animals, but regarded as something different.

Vasquez (1985) found that in drawings of micro-organisms there were associations with other small living organisms e.g. flies, other insects and toads. These findings were particularly apparent in drawings from younger children, aged 12-13 years, whereas older children, aged 14-15 years were more likely to draw ovals or circles more consistently. Nagy (1953) found a small percentage of 5-7-year-olds drew a germ with an animal-like appearance, although there was a tendency for the younger children in her study to draw abstract figures such as points, circles and parallelograms. Abstract figures seem to give way to animal figures with chronological age, which seems surprising, although as Nagy explains, younger children may have no concrete representation of germs, hence the abstract drawings. As children's biological knowledge increases, they are developing their concept of living, as well as that of animal (Piaget, 1929; Tamir *et al.*, 1981; Carey, 1985; Trowbridge and Mintzes, 1985; Osborne *et al.*, 1992; Braund, 1998; Tunnicliffe and Reiss, 1999; Shephardson, 2002) and the closest point of reference children may have for germs, at this stage, is that of an animal.

Nagy (1953) found that germs were also considered to be one single species, whereas when animals were drawn to depict germs a definite species was presented; for example, a fly, or a worm. Arthropods were most frequently cited, although other invertebrates such as worms were also mentioned frequently. Some children considered germs were not a special kind of animal, but were identified with a definite animal species; for example, a boy aged 10.9 years said, *'I have drawn some germs. The first one is a water spider. The second one is a mosquito. The third one is a kind of a flea', (*Nagy, 1953:233). Others consider germs to be animal-like, as this eight year old says, *'I think that germs are little insects with legs and something like ants, only much smaller', (*Nagy, 1953:234). Nagy explains, the association of germs with animals is not surprising as ideas about infection and illness, dirt and smells obtained from home, cartoons and health education posters provide children with everyday experiences to associate micro-organisms with animals. Nagy refers to this type of ontological reasoning as the principle of spatial identity.

The children in Maxted's (1984) study frequently associated micro-organisms with animals, although they were recognized as quite separate and distinct from them. The majority of students interviewed by Simonneaux (1996, 2000) share this view. They consider bacteria to be neither plants nor animals. Although, many responses indicate that these students would more readily associate bacteria with animals, or as being animal-like, this suggests that older children also have difficulty in classifying micro-organisms:

> Bacteria, I would put them as animals. I would rather put them on the animal side than on the plant side...But, I would not put them with plants, the bacteria, I would rather put them with the animals, but... not with the animals, more on the animal side. Without being a real animal. (Simonneaux, 1996:38).

Viruses seem to cause even more problems in terms of their classification. The pupils in Simonneaux's study thought viruses have plant and animal-like characteristics, such as being noxious like a plant, or moving like an animal, although a great deal of confusion exists, as this pupil indicates:

> I'd say a virus is closer to an animal, but I don't think it is an animal, it's not a plant.... maybe a fungus.....because a fungus is a kind of disease... it's half way between, half man half biscuit, well half plant and half animal. (Simonneaux, 2000: 637).

The terms children employ, how they group micro-organisms and their attempts to articulate the relationship between different kinds of micro-organisms indicates that confusion exists, and that children from the ages of 5 to16 years have difficulty in classifying micro-organisms in an accepted scientific manner. This is not surprising, given the difficulties scientists have in classifying micro-organisms noted in section 2.10 later in the chapter and children's difficulties may be exacerbated by a lack of specific teaching.

2.4 Morphology

Nagy (1953) showed that half of the children between the ages of 5 and 7 years in her study could not conceptualize what they thought a germ would look like when asked to draw a germ. Of those that did attempt a drawing, the majority provided abstract figures, such as dots, roundish, or angular figures, whilst some drew animals. Children between the ages of 8 and 11 years also included abstract figures, such as points circles and parallelograms, but the frequency of these abstract figures seems to reduce with age and germs were more frequently represented as animals. The response by children in Vasquez's (1985) study indicates that the younger children, 12-13 years, depicted micro-organisms, as circular or irregular shapes and gave their drawings animal-like characteristics, such as legs, or they drew animals; for example;. a toad or a worm. The older pupils (14-15 years) in the same study drew a wider variety of homologous shapes; for example, round, or oval and often depicted them in a group 'under' a microscope, or associated with a substrate ; for example, on a bit of food, or in a drop of water. Whilst many of these representations are far from scientific reality, the children in Nagy's (1953)and Vasquez's(1985) studies that drew micro-organisms as shapes rather than animals, drew repeated representations as if they were aware that micro-organisms were rarely found individually. However, it is dangerous to speculate too far, and, as Nagy suggests, it would seem to be more likely that there is a semantic reason for this; for example, 'germs' are often referred to in the plural, but 'animal' is not. Other ideas about bacterial appearance may come from direct observation of cultures and microscopic slides. In these instances students tended to describe them by their form and colour; for example, *'spherical; long and sharp; white; a sort of spot'* (Simonneaux, 1996:31).

Vasquez (1985) showed, whilst children may be beginning to grasp the concept of the unicellular nature of micro-organisms, they did not have any notion of what was contained within the structure they had drawn. Most children considered it to be 'empty'. The students in Simonneaux's (2000) study considered that bacteria can be 'empty' or 'full' depending on whether they have been able to feed or not. These ideas indicate incomplete understanding of the structure of unicellular organisms and their associated physiological actions, as well as fragmented and incomplete ideas about life and living processes. Simonneaux (2000) found that viruses were readily associated with cells and cellular structure. Viruses were considered to multiply by cell division and to contain a nucleus. Some students thought viruses and bacteria are interchangeable; both are thought to be a type of cell; because of this, they were considered to have a spherical shape and contain a nucleus, which was referred to as, *'the heart'* (Simmoneaux, 2000:624). This indicates some knowledge about living organisms and the importance of the nucleus i.e. because bacteria and viruses are thought to be living they must be cellular and contain a nucleus. However, this reasoning is not only incomplete, but also anthropomorphic in nature. Other responses at first used some scientific knowledge, but these were altered because of negative opinions about bacteria; for example, that bacteria have a harmful liquid inside them, which is thought to be poisonous. Initially, the students considered that bacteria were cells, which have a positive role, but they changed their views because bacteria were not thought to have a positive role.

In a much larger study of 482 British students aged 15-16 years, Lewis *et al.* (1997) found that 48.1% considered bacteria to be unicellular organisms, 36.0% thought they were multi-cellular and 3.6% thought that they were not cellular at all. The same percentage of the group thought viruses were multi-cellular and 38.1% considered them to be unicellular, whilst 5.7% thought they were non-cellular. This study, unusually, also asked about fungi: 56.5 % thought they were multi-cellular; 21.9% thought they were unicellular and 4.9% thought they were non-cellular.

In the same study by Lewis *et al.* students were also asked about the presence or absence of chromosomes. They found that 35.3% thought that viruses contained chromosomes, 41.5% thought bacteria did and 40.8% that fungi did, although levels of uncertainty were high, with about one third of the cohort indicating that they did not know. When asked if bacteria, viruses and fungi contained genetic material, more students thought that micro-organisms contain genetic material, even though it isn't contained within chromosomes. This is scientifically valid for viruses, which do not have chromosomes and also for bacteria that have a simple circle of DNA, although this is often referred to as a chromosome. However, whether these students are aware of the structure of viruses and bacteria is not certain. The assertion that bacteria and viruses contain chromosomes seems to be more closely connected with ideas that they may be considered as an animal. There also seems to be confusion about the relationship between genetic material and chromosomes: 11% of the cohort thought that bacteria could have chromosomes without having any genetic information; 40% thought that viruses did not contain either. This suggests that these students either do not consider these organisms to be living, or that all living things do not need to contain genetic information. These views have serious implications for students' understanding of gene technology.

It appears that the structure of micro-organisms is poorly understood and that children's ideas are confused, although there does seem to be a change in ideas as children get older. Very young children seem unable to conceptualize what a micro-organism might look like, which, as Nagy (1953) suggests, may be because the term she used, 'germ', has no real meaning for this age group. As children's biological understanding develops, micro-organisms tend to be represented as animals, or animal-like, and this idea remains with some until they are at the latter end of secondary school. However, many children's ideas seem to have developed with age and the evidence suggests that some considered micro-organisms to be a single cell-like entity, although their external and internal structure does not appear to be well understood. This may be due to lack of explicit teaching about cells and cellular structure (Lewis *et al.*, 1997). It seems that the extent of children's understanding of the structure of micro-organisms is something worthy of further exploration.

2.5 The living and non-living state

Whether something is alive or not is a highly complex concept and includes criteria, such as the seven traditional living processes of movement, respiration, irritability, growth, reproduction, excretion and nutrition, cellular structure, the presence of particular biological molecules e.g. DNA, functional proteins and cellular respiration (Brumby, 1982). It therefore requires a sophisticated interaction of ideas within an individual's mind, and it has been considered by some that children are not capable of this complexity of thought (Looft, 1974; Smeets, 1974). However, the richness of children's responses as an indication of insight to the question of whether something is alive or not, has often been ignored by some researchers, (Lucas *et al.*, 1979).

The concept of 'alive' is often connected naively with the more obvious living processes, such as movement and growth, and does not necessarily include less obvious concepts; such as, dormancy, sporulation, embryology, or dependency on energy transformations (Tamir *et al.*, 1981; Brumby, 1982; O-saki and Samiroden, 1990). Piaget (1929) suggested that very young children consistently use movement as a criterion for an object being alive. He also posited that children develop their ideas about whether something is alive or not in a sequential manner; according to their age and stage of development, these are described as:

- Stage A (age 6-7 years), in which an object demonstrating some activity such as making a noise or falling down is considered to be alive;
- Stage B (age 8-9 years), in which life is identified by movement, and any moving object is considered to be alive;

- Stage C (age 9-11 years), in which only things which exhibit spontaneous movement (sun, wind, river) are considered to be alive and have consciousness;
- Stage D (age 11 years and up), in which children correctly identify only living creatures as being alive and possessing consciousness.

Piaget's stages of development have been criticized for their deterministic and restrictive ideas about children's learning and development (Carey, 1985; Osborne *et al.*, 1992) and later studies have attempted to discover the nature of children's understanding through consideration of the processes of living things, rather than a simplistic categorization as living or non-living. Nevertheless, Piaget's work still has relevance (e.g.O-saki and Samiroden, D, 1990). The literature discussed below indicates that children do regard movement as a key criterion of whether something, including a micro-organism, is alive or not.

Tamir *et al.* (1981) found that in a cross-age study of 424 Israeli students, from grades 3 to 9, no statistically significant differences were evident in classifying items as living or non-living, nor were they related to ability in science. Living processes (growth and development, nutrition, respiration, reproduction, death, movement) tended to be referred to more often by older students to classify plants, animals and embryos and less often for inanimate objects. Brumby (1982) quite rightly argues that these references are more reminiscent of primary science. It would appear that older pupils and students do not readily employ all of their knowledge, or do not apply it in unfamiliar contexts. Tamir *et al.* (1981) found that those pupils from agricultural backgrounds were more likely to state that seeds and eggs were alive; it would seem that ontological reasoning and direct experience is important in enabling children to classify objects as living or not. Osborne *et al.* (1992) suggest that children distinguish between living and non-living based on a combination of criteria that include behaviour, external structure and internal structure. It appears that children do not always use the same life processes criteria to categorise living and non-living as biologists do, but their understanding of 'alive' and 'not alive' becomes more sophisticated with age and is fundamentally determined by increased domain specific biological knowledge (Carey, 1985; Osborne *et al.*1992).

Animate and inanimate objects are frequently given anthropomorphic characteristics (Tamir *et al.*, 1981). Even after many years of school biology, students' concept of life is distinctly anthropomorphic (Brumby, 1982). These attributes range from providing the object with free will, a soul, or human emotions (Tamir *et al.*, 1981) to having physical human features such as a face, or indeed being referred to as, 'he', or, 'she'.

Research studies indicate that children and adults of different ages and in different countries generally consider micro-organisms to be living; for example, 8-11-year-olds in Britain and 5-7-year-olds in America (Nagy, 1953),12-13-year-olds in England (Maxted ,1984), 12-15-year-olds in France (Vasquez, 1985), 15-year-olds in England (Prout, 1985), young adults, 18-25-year-olds in France (Rene and Guilbert,1994), French workers in the agro-food industry (Bazile, 1994), 15-16-year-olds in France (Simonneaux, 2000) and 7-14-year-olds in England (Byrne and Sharp, 2006). Many quoted movement as a key characteristic, although feeding and virulence were also common reasons for asserting micro-organisms are alive.

Vasquez (1985) administered a questionnaire to two separate groups, one a class of 12-13-year-olds, and the other a class of 14-15-year-olds. She noted that the concept of living is not well established by children, even in their secondary school years and therefore being able to ascribe features of living to micro-organisms proved difficult. Whilst children did regard micro-organisms as living the reasons were confused. When asked the question, 'is a germ living?' pupils readily quoted movement as a positive assertion that micro-organisms are alive. In addition, alternative reasons were offered by some pupils, who suggested that germs eat, multiply and die; whilst a few stated that germs were sensitive to their environment, which indicates that these pupils have a more sophisticated notion of the concept of living. However, when the children were asked the question, 'how do they live?' many children did not know the answer and provided a number of ideas, such as *'in a society', 'by eating something', 'in our body'* (Vasquez,1985:35). Pathogenic microbes were thought to be absolute opportunists, because they were thought to live with everything that is useful like air, water and humidity.

Maxted (1984) used interviews, in a class of 31 pupils aged 12-13 years, to elicit their ideas about germs or bacteria. She found that all pupils thought that germs or bacteria were alive, although their reasoning for asserting this was not coherent. Only two pupils identified three activities of living organisms; movement, eating and reproduction, but they did not use these as reasons for bacteria being alive. Instead, they ascribed alternative and anthropocentric reasons; for example, the omnipresence of bacteria on their teeth as an indication of living, because even if teeth were brushed the bacteria would continuously return, suggesting that the bacteria have free will. The attributes of living things, rather than the characteristics of live micro-organisms were also evident, such as the idea that viruses eat blood cells and that bacteria grow and become, '*bigger like families do, you know they were reproducing and that*' (Maxted,1984:72). Other anthropocentric reasons unrelated to the scientific notion of living were given; for example, bacteria living in your throat, because they wouldn't know where else to go. Five pupils also considered bacteria were living, because they cause disease.

Simonneaux (2000) found that bacteria and viruses were thought to be living, by all ten of the 15-16-year-old pupils she interviewed. Even though these students had been taught about micro-organisms in the previous year, their reasoning was very varied. Drawing on analogies with cells, viruses were considered to have a nucleus by three pupils and one of them followed an anthropomorphic line of reasoning, suggesting that the nucleus in the middle is the heart and that muscles enable the virus to move. Others also considered bacteria and viruses to be alive because they are capable of independent movement and consequently possess a muscle around the heart. Some students seemed to apply scientific knowledge in conjunction with their opinion, initially likening bacteria to cells and giving them a nucleus; however unlike cells, bacteria were considered to play a negative role and one student suggested that bacteria were filled with a liquid, like venom, but were still thought to be alive. Viruses and bacteria are also cited as engaging in feeding and multiplication activities, often from an anthropomorphic point of view. Viruses are considered to be more harmful than bacteria, although both are associated with being alive because they are active and attack living organisms, which they feed upon and subsequently grow and multiply.

Nagy (1953) used four different techniques: an essay, drawings, tests and interviews to establish how children in two separate age groups represented germs. Over 50% of the children, in both the 5-7-year-old and 8-11-year-old age groups, considered 'germs' as living inside a person because they walk around, eat and breed. Whilst these activities were regarded as indicators that the germs were alive, it was noted that the predominant notion was that they were hazardous to the individual. Young children also related germs to inanimate items such as dust, dirt or poison (Nagy, 1953; Leach *et al.*, 1996) and may make no distinction between them (Kalish, 1999; Solomon and Cassimatis, 1999).

Most of the literature reviewed suggests that children consider micro-organisms to be living because they are capable of independent movement. The notion that micro-organisms are active, aggressive, parasitic agents which attack other living organisms and feed on them, breed, or multiply is also common amongst children's ideas. Micro-organisms are also considered to be alive because they cause disease, although this is not always associated with other reasons for being alive. Micro-organisms are often provided with anthropomorphic characteristics to justify, or reason that they are alive. The findings discussed here are reminiscent of work about children's concepts of life and living with respect to other organisms. It may be that children's ideas about micro-organisms are also dependent upon maturity and the development of biological knowledge.

2.6 Size and scale

The idea that bacteria, viruses and germs are small living organisms too tiny to be seen with the naked eye seems to be generally well established in all ages of children and adults who have taken part in the research reviewed here. However, children's knowledge and understanding about the actual and relative size of micro-organisms, as well as their structure and morphology, is varied and tends to be different from the scientifically accepted view.

Even very young children seem to be intuitively able to imagine very small objects (Boulter, 1997; Byrne and Sharp, 2006), although they have difficulty in attaching a specific unit of measurement to the object, or in providing an accurate idea of the scale of magnified objects (Marsh *et al.*, 2001). Older children have been found to have difficulty in understanding microscopic representations, for example in chemistry (Ben-Zvi *et al.*, 1986). It is therefore unsurprising that children find it complicated to conceptualize the actual and relative size of micro-organisms. Pupils of different ages consider that micro-organisms are small, light and float around in the air like dust particles. A boy in Nagy's study (1953:234) typifies many responses, *'I should imagine they are like tiny pieces of dirt that we cannot see in the air'.* Vasquez (1985) indicates that children show they are aware of their microscopic size by drawing them under a microscope or magnifying glass. Maxted's pupils (1984) thought that bacteria could only be seen with the aid of a microscope. Simonneaux's (2000) students were unanimous in their view that bacteria and viruses are extremely small and cannot be seen with the naked eye. Some of Simonneaux's students attempted to provide some notion of size, suggesting a range of ideas; for example, a few microns, 0.2 micron, 10-7mm and so on. She considered these attempts at some scientific accuracy were because students knew that microns were very small and this was the smallest unit of measurement of which they had heard, rather than a true reflection of their understanding of the size. Perhaps it is not surprising that one respondent in Simonneaux's study suggested that viruses were about the size of an atom.

2.7 Disease, health and infection control

Medical as well as commercial material and the media often portray micro-organisms as dangerous and potentially fatal. It is therefore not surprising to find that children and adults hold ideas that micro-organisms are harmful, especially to humans, because they cause disease and illness.

2.7.1 Micro-organisms as causal agents of disease

The pathogenic view of micro-organisms by people of different ages is well documented, (Nagy, 1951; 1953; Maxted, 1984; Prout, 1985; Vasquez, 1985; Keil, 1992; Springer and Ruckel, 1992; Rene and Guilbert, 1994; Bazile, 1994; Au and Romo, 1996; Kalish, 1996a; 1996b; Simonneaux, 2000). Nagy (1953) found that children aged between 5 and 11 years considered that germs made them ill and 43 kinds of illness were enumerated. Chickenpox, measles, scarlet fever, colds and skin troubles were the most frequently cited , although the term 'germ(s)' was used generically, as if there were a single species that caused all the diseases mentioned. The children seemed to be unaware that each disease is caused by a specific pathogen. Keil's (1992) findings would concur to some extent with this view. He found that young children (5-6 years) thought all diseases with similar symptoms were the same and it was not until children were 9-10 years old that causal reasons were used to distinguish one illness from another. In contrast, half of the pupils in Maxted's study thought that different types of germs caused different kinds of diseases. However, as Driver *et al.* (1994) comment, there is insufficient data to know if these differences can be attributed to progression of children's understanding with age, or the date of the studies. Simonneaux (2000) found that students thought that viruses were more pathogenic and dangerous to humans compared to bacteria. Bacteria were thought to be connected to less dangerous diseases than viruses and tended to attack the outside of the body, especially the skin, whereas viruses were definitely connected with internal attack, cellular disruption and digestion. Bacteria were considered to cause mild health problems such as colds, 'flu, or sneezing but they could be easily eliminated. Following an anthropocentric line of reasoning bacteria were thought to be vulnerable and to take risks when they attack a person. Viruses, on the other hand, were thought to have a strategy, a kind of '*hostile intelligence*' (Simmoneaux, 2000: 627), which they could employ to proliferate inside the body and which the body was unable to prevent. The students in Simonneaux's study do not appear to relate virulence to specific micro-organisms. It is the rate at which they can multiply and the numbers present that are thought to indicate how dangerous they are. For example, bacteria were thought to be inert and only become active when there are lots of them and the greater the numbers of hostile viruses present, the more powerful they will be (Simonneaux, 2000).

Modes of infection focus on physical contact with sick people (Vasquez, 1985; Simonneaux, 2000), via the mouth, breathing or through the skin (Nagy 1953). Although the vast majority (79.29%) of 8 to11-year-olds referred to eating something as a way of becoming infected with germs and very young children seemed to equate the mere presence of germs with illness. In their work with pre-school children, aged 4-5 years, Springer and Ruckel (1992) and Kalish (1996b) found that the children overestimated the likelihood of illness if there was explicit reference to germs in the stories they told.

Furthermore, several studies have shown that children consider all illnesses as infectious and germs are thought to be the causal agent. No distinction between contagious and non-contagious diseases and no reference to organic and functional diseases or dietary deficiencies were made (Nagy, 1951; Bibace and Walsh, 1980; Hergenrather and Rabinowitz, 1991). This type of thinking is analogous to 'microbe-mania' (Raichvarg, 1995) where, after the discovery of micro-organisms by Pasteur, the germ theory of disease became the predominant idea in nineteenth-century Europe, and any illness was potentially linked to germs as infectious agents. However, Kalish (1999) suggests that this is due to an over-extension of children's causal reasoning, rather than their transductive or magical thinking. Kalish (1999) criticizes the existing research for extrapolating a general conclusion that children think all illnesses are caused by micro-organisms from asking them about specific illnesses. He goes on to point out that; pre-school children did not seem to identify illness with a particular causal model. However, he acknowledges there are no conclusive findings to suggest that young school-aged children recognized any causal agent of disease other than micro-organisms. There appears to be resistance to accepting ideas other than Pasteur's notion of disease as something that is fundamentally exogenous, in that healthy individuals are attacked by exogenous micro-organisms (Rumelhard, 1986; Simonneaux, 2000). This has implications for students' ability to understand and appreciate the ethical implications of biotechnological /biomedical techniques such as antenatal screening that raises many sensitive issues surrounding genetic disease (Simonneaux, 2000). In contrast to Rumelhard's and Simonneaux's view, Bibace and Walsh (1980), Kalish (1999) and Hergenrather and Rabinowitz (1991) suggest that younger children eventually give up their single causal model of illness and accept the notion of multiple causes, in much the same way as adults and young adolescents do.

2.7.2 Micro-organisms as harmful agents

Alongside the ideas presented in the previous section, there is a commonly held associated view that micro-organisms are harmful to other organisms especially humans. Nagy (1953) found that children aged 8-10 years thought germs caused harm, which was not necessarily articulated as disease or illness, but more as damage to the body, or in extreme circumstances, death. The damage was achieved through the germs' activities inside the body, such as, walking about, eating and breeding. The notion of micro-organisms causing physical damage to the body is also prevalent in the ideas of Simonneaux's (2000) students. When she asked her students to represent viruses and bacteria for a comic strip in an attempt to evoke emotions and feelings about these organisms, the students produced pictures that depicted their views about the aggressive and vicious nature of viruses and bacteria. Viruses were depicted as little devils with a pitchfork killing everything, or with lots of arms and syringes, snakes, or something rather nasty, or with teeth to indicate how easily they could devour cells. Bacteria were considered to be less vicious than viruses, but still regarded as dangerous. The relationship between other agents which are regarded as harmful, for example, poison, venom, dirt, dust or snakes, with some children likening micro-organisms to these items, has been noted elsewhere in this chapter.

2.7.3 Infection, recovery and immunity

Au *et al.* (1999) point out that knowing that micro-organisms can cause illness is far from knowing how they make people sick. Au and Romo (1999) found that only 6% of the children between 5 and 13 years participating in their study mentioned that the 'incubation of germs' accounts for the time lag between initial infection and the onset of the symptoms of illness. It would seem that children lack an inherent biological understanding of germs (Au and Romo, 1996, 1999; Kalish, 1997; Solomon and Cassimatis, 1999). Other studies support this view; the children in Nagy's study (1953) and the 16-17-year-olds studied by Barenholz and Tamir (1987) considered that both infection and subsequent recovery are automatic upon the receipt of the germ and consequent application of a medicine. The ideas, mentioned earlier, that micro-organisms feed on and multiply in the body seem to be related to their survival, rather than having any physiological effect on their host. Nagy's pupils mentioned no other conditioning factors, such as the kind and degree of infection, hereditary and present status of the body. Inagaki and Hatano (1993) comment that the prevalence of the germ theory of disease in Western medicine and the exclusion of bodily or psychological factors contributing to susceptibility to illness may explain why vitalistic explanations of disease are not commonly referred to by children living in the 'industrial west', although this may not be the case in Japan (Inagaki and Hatano, 2002).

The notion that once micro-organisms have entered the body, illness is inevitable seems to be well established, although older children also hold ideas about the immune system and that the body will respond to infection. Maxted (1984) found some pupils were aware that the body has some kind of defence system against pathogens and a few mentioned immunity (two pupils), one pupil mentioned antibodies and another talked about antibiotics. Maxted goes on to comment, that pupils had at least heard of immunity and antibodies, although there is little indication that these concepts are understood. Vasquez (1985) found that both the 12-13-year-olds and 14-15-year-olds knew about contagious diseases. The younger pupils talked about the body having a natural defence that moves around in the blood, whilst the older pupils described the organism's reaction to a foreign body as a fight in which the germs attack the cells and the body defends itself. They also consider that if the germs are too numerous the cells will become outnumbered and the person will die. Prout (1985) found that just under half of the 15-year-olds, in his study about knowledge and understanding of the common cold, had a simple idea of resistance to infection. They considered that people have some kind of defence system to ward off illness, although only 30%

were able to associate this with the blood stream. The cells in the blood stream were seen as fighting the infection by gathering round the micro-organisms in a big cluster, pouncing on and eating them up. Analogies with a pitched battle, in which the body has defence agents to fight the intrusive agents, were also commonly used by Simonneaux's students (2000) in attempts to explain both infection and subsequent immune response. Rumelhard (1986) indicates that the war-like vocabulary used to explain what is happening is important in understanding immune phenomena in which disease is seen as fundamentally exogenous, although this conception contributes to a body of alternative knowledge where the body's immune system is personalized and behaves in a war-like manner (Simonneaux, 2000). Other ideas about the immune system were connected with rejection of what is alien to self and hygiene (Simonneaux, 2000). This aspect of hygiene is based on the association with micro-organisms and dirt or impurities, where the immune system eliminates dirt or cleanses the body of dirty and alien items. Antibodies were described as particles, elements, white cells or molecules which defend the body against germs and diseases and were thought to be akin to medicines as the same role was attributed to them, albeit a kind of self-medication. The antibody/antigen reaction was clearly related to specific infection by these students and they did not seem to be aware of non-specific immune responses. Alternative ideas about immunity were cited by 30% of the 15-year-olds in Prout's study (1985). Physical conditions alone, such as good food and warm houses were considered to be elements in resistance to infection. Similarly, the immune defences were considered to be enhanced if people kept fit, wore warm clothes, or ate properly. However, it is unclear whether these pupils are referring to an alternative model of health in which lifestyle is paramount to staying healthy (Simonneaux 2000).

Younger children seem to retain the notion of automatic infection and healing until the end of childhood at 11 years old (Nagy 1953). The children in Nagy's study correspond in age to the children in Key Stages 1 and 2 in this study. None of the children in Nagy's study had any conception of the immune system. As mentioned previously, where illness was thought to be an inevitable consequence of germs entering the body, the exit of germs from the body caused automatic healing. Germs were thought to leave the body through the nose and mouth by breathing, sneezing and vomiting and anal evacuation although no explanations for their exit were provided. The only reference to the healing process, other than exit from the body, was in connection with medication from the doctor. The medicine is seen as an agent to physically remove the germs from the body and thus cause healing, as this nine-year-old says, *'the medicine cures the body and it washes the dirt away'* (Nagy, 1953:238).

The notion that infection is strongly associated with micro-organisms is a key theme within the literature. However, alternative ideas about the cause of infection also prevail and these ideas often seem to be held in conjunction with the biomedical view of disease. Maxted (1984) found that pupils thought that in addition to bacteria, or germs, causing diseases, environmental circumstances, such as getting cold, or cold weather, or washing hair and then going out, could also cause a cold. The pre-school children in MacMenamy and Wiser's study (1997) considered that cold air is contagious and that this can cause illness independently of germs. Prout (1985) also showed that children (and adults) hold on to the folk lore version of diseases and their transmission, alongside a germ theory of disease. Even after considerable instruction they still tend to revert to non-scientific ideas, 23% of the respondents thought that germs worked alongside alternative factors such as getting cold but the largest proportion, 59%, put forward germ and non-germ theories as plausible separate causes. Different kinds of cold were referred to and the notion that some people were more prone to one type than another was suggested. A small percentage (11%) thought that environmental conditions alone were the cause of a cold. The issue of everyday language and meaning compared to scientific terminology is apparent. As Helman (1978) suggests the folk model of infection is very persistent and Driver *et al.* (1994) consider that the term 'cold' reinforces the connection with the environment. With reference to the common cold, Helman (1978) points out that the subjective states associated with a cold are seen as the consequence of interaction with the natural environment. The cold penetrates part of the body and causes symptoms, especially if the individual moves from a hot to a cold region. Remedies for the cold may also contribute to alternative ideas, as they emphasize a rebalancing of temperature; for example, having hot drinks to restore the counter effects of getting cold. Helman (1978) goes on to suggest that rather than folklore ideas being ousted by germ theory, each has accommodated to the other and, whilst biomedical terminology has become familiar, the concepts are confused.

The effect of medication, cures and prevention of diseases does not seem to be well understood by pupils in the studies available. Many of the pupils in Prout's (1985) study were unclear about the difference between cure and relief of symptoms for the common cold. Their views seemed to depend upon whether they thought the medication would work or not. There was little knowledge of what the remedies contained, other than chemicals that killed the germs and everyday experience was used to explain why the medicine would work or not, although some inventive reasons were also used; *'It's a drug that kills the germs but it's only there in small quantities so therefore it doesn't always work'* (Prout, 1985:400). Antibiotics were understood, by 77% of the pupils in Prout's study, to be drugs that treat infections, although 21% could not say what an antibiotic was. Antibiotics were thought to be used only to treat serious infections; the fact that they were available only on prescription added to this view (Prout, 1985; Barenholz and Tamir, 1987). It was this view, about their potency, rather than an understanding of antibiotic function and viral disease that led these pupils to consider that they would be wasted on treating everyday illnesses like the common cold. Antibiotics were considered to be curative rather than preventative drugs, although they are also thought to contribute to strengthening the immune system, rather than acting on the micro-organisms. For some students, antibiotics and antibodies are regarded as the same thing (Simonneaux, 1996). Vaccinations and drugs were considered to be means of protecting the body from infection and students referred to them as, *'little doses of illness',* and, *'weakened bacteria'* (Simmoneaux, 1996:10), although no further explanations of the processes were offered and scientific knowledge seemed to be fragmented. Other students confused vaccine with serum by suggesting that a vaccine corresponds to an injection of antibodies. Maxted (1984) found that children considered that germs could be used to make medicines or vaccinations when they were dead or killed, but like Simonneaux's students they did not provide further explanation.

2.8 Ecology and ecosystems

The ubiquity of micro-organisms, especially bacteria is well established; they are found in every ecosystem and even in the most inhospitable conditions from the hottest rocks and springs to the coldest ocean. The adaptability of these amazing organisms and their beneficial metabolic processes is one that should be celebrated and enjoyed. However, it would appear that most people consider all micro-organisms to be harmful and their omnipresence to be a threat to human health. That they should be avoided or, even better, eliminated is a commonly held notion.

2.8.1 Location

Maxted (1984) found that children provided a range of ideas about where they would find bacteria. Suggestions were, in the air, in animals' bodies, everywhere, in the earth, or dirt, on skin, in water and in blood. Vasquez (1985) also found that pupils thought micro-organisms could be found everywhere and they gave specific examples, which included, the sun, the air, the water, dustbins, town pollution and from our bodies because of poor hygiene. They also thought that micro-organisms could proliferate with ease in all favourable conditions adding to the notion that they are everywhere. According to Simonneaux (2000), students consider bacteria are to be found in a variety of places, such as damp conditions, in the soil, the air and in cool conditions, and they are closely associated with the human body. Some of these students think that bacteria can be found everywhere, although extreme temperatures would not be favourable for bacterial existence. Specific unhygienic conditions such as decomposing, or contaminated food are also mentioned (Brinkman and Boschhuizen, 1989; Simmoneaux, 2000). Bacteria were also seen as 'dirt' and associated the urban environment and pollution and even as a contributing factor to pollution in more rural environments. The younger children in Nagy's study have a more restricted set of ideas. They consider germs to be associated with the human body and to have bad, dirty, or unpleasant associations (Nagy, 1951). Whilst the idea that micro-organisms can be found everywhere is frequently cited, reasoning is limited and it seems that microbial ubiquity is considered only as posing a threat to humans as well as other living organisms. The relationship between micro-organisms and dirty and unhygienic conditions appears to be well established and is closely linked to the predominance of micro-organism as the agents of disease. In addition, the idea that all micro-organisms can be avoided or destroyed through hygienic practices, the use of disinfectant or sterilization prevails (Simonneaux, 2000) and the elimination of all micro-organisms was thought to be a worthwhile goal (Brinkman and Boschhiuzen, 1989).

2.8.2 Ecosystems and the cycling of matter

As Postgate (2000) says, the chemical balance of the biosphere and hence the existence of the living organisms that make it up depends upon complex biochemical reactions to recycle nutrients. Micro-organisms play a vital role within these cycles; multi-cellular plants and animals would not exist without the metabolic processes of many different micro-organisms. At a basic level, without microbial action to break down complex organic materials, the life of larger organisms would have ceased long ago, as the important nutrients to recreate and sustain life would have been locked in the bodies of these dead plants and animals. It is easy to imagine what would happen if; for example, leaves falling off trees in autumn did not decay. School biology and school texts tend to deal with specific processes, such as respiration, photosynthesis, decay and cycling of matter separately, with little emphasis on the relationship between them (Lin and Hu, 2003) and this can lead to fragmented knowledge about these interconnected concepts (Waheed and Lucas,1992). Leach *et al.* (1992) also noted that many secondary science teachers in England do not address the decay process directly, as it relates to its role in the cycling of matter, during teaching. It is therefore hardly surprising that the importance of microbial activity, in nutrient cycling, in order to sustain life on the planet tends to be overlooked. In addition, the prevalent notion that micro-organisms are inherently bad may prevent children from understanding the vital role they play in the ecological balance (Vasquez, 1985).

a. The process of decay

Whilst microbial involvement in decomposition is recognized by some pupils, the processes of decay and microbial activity are not well understood. Sequeira and Freitas (1986); Smith and Anderson (1986); Leach *et al.* (1996); Hellden (1996) and Hogan and Fisherkeller (1996) have shown that many children across the primary and secondary age range consider that decomposition is a mysterious process in which matter simply disappears, melts, or disintegrates into smaller and smaller pieces.

In a cross-age study of pupils aged 5-16 years, Leach *et al.* (1996) used two probes, a photograph of a decaying apple and a video showing fruit decaying to elicit children's ideas about the cause of decay and their views about what would ultimately happen to the matter from the decaying object. They found that as children got older they used progressively sophisticated language to describe the objects for example, *'bad', 'rotten', 'decaying'*, and, *'decomposing'* (Leach *et al.*,1996:7), which could be used to explain the scientific process of decay. However, just because children can use more technical terms it does not mean that they have any greater understanding of the processes involved. Some children could not provide any causes for the decay, whilst others cited one or more factors. Five different categories of the causes of decay emerged from the analysis of children's explanations. Explanations increased with age and fewer children in all age groups explained decay in terms of microbial activity, compared to 'natural' causes. Germs, micro-organisms, bacteria, or other decomposers, were described as attacking, or eating, the apple and whilst this reason increased with age many children did not consider the role of micro-organisms in decay. Leach *et al.* (1996) suggest that 10% of 5 to7-year-olds spontaneously mentioning germs as a cause of decay may have more to do with everyday associations, such as being told not to eat an item of food after it has fallen on the floor, because it has germs on it, rather than understanding the role of micro-organisms in the decay process. Older children also tended to provide multiple explanations, compared to the single reasons from younger children, although they were listed as separate entities and the interrelation between physical factors, such as temperature and moisture on microbial and enzymatic action, was not acknowledged, even by the oldest children in the study.

The notion that micro-organisms do not play a significant part in the decay process accords with the findings of Smith and Anderson (1986). In their study of 12-year-olds, children saw decay as a process, which either did not involve other organisms at all, or saw decay as an inevitable consequence of time. In both explanations the children considered that the decomposed matter from dead organisms would enrich the soil. In a study to discover Portuguese children's ideas about decomposition, Sequeira and Freitas (1986) found that 8-13-year-olds' responses were similar to those of Leach *et al.* (1996). The children in their study suggested that organic matter was eaten, worn out, gone to pieces, rotted, or disappeared into the sky, and the importance of micro-organisms was only mentioned by a few children. Hellden (1996) found that 9-year-olds in Sweden, considered that organic matter; for example leaves, just disappeared by getting smaller and smaller or blew away and they thought that decomposition occurred without any activity from organisms, microbial or other, although woodlice could be responsible for some sort of fragmentation. Older children (11-year-olds), in Hellden's study, thought that leaves, paper, wood and grass would be converted into soil. The soil became the end point of the process and not an essential stage in the cycling of organic nutrients. On this assumption about one third of the class thought the Earth would increase in size every year, as a result of the decomposition of the leaves. Other children saw the Earth as a large container in which all the 'new' soil fills hollows and becomes compressed, or that the matter would blow away or be eaten by animals or burned. It seems that these children intuitively knew that an increase in the size of the Earth is not possible and so they offered alternative explanations about the fate of the products of decomposition.

b. Cycling of matter

The idea that plants and animals can be broken down seems to be generally accepted by children. However, the fate of the products of decomposition is a more difficult concept for children to comprehend, because they cannot see the process of gaseous exchange and therefore, for them, it doesn't exist (Hellden, 1996). Hellden found that children considered that the soil was the end point for decomposition, rather than being a stage in the cycling of matter and, whilst biomass would be conserved, there would be less than existed previously. As Hellden (1996) suggests, the process of conservation of matter is not well understood. Leach *et al.* (1992) also found that few 16-year-olds in their study had notions of conservation in relation to decay and other concepts, such as photosynthesis, food assimilation and respiration. More recently, Lin and Hu (2003) showed that the 13-year-olds in their study have weak knowledge about the interconnectedness of biological processes in relation to energy flow and cycling of matter and that the most difficult concepts to comprehend were those involving the living and non-living world. Children seem to have little or no understanding that organic matter is broken down to inorganic matter, which becomes available to other living organisms, or of the role that micro-organisms play in these processes. However, Hogan and Fisherkeller (1996) noted that children who assimilated new knowledge about micro-organisms as agents of decomposition and decay were able to use this knowledge to develop ideas about nutrient cycling within ecosystems. Hogan and Fisherkeller go on to suggest that teaching about decomposition might form a bridge to understanding the more abstract concepts of nutrient recycling.

2.9 Technological applications

The term, 'biotechnology', can be attributed to those biologically based technologies; for example, cell biology, cloning, food production and genetic engineering, which make use of the organisms themselves or the products of their metabolism for use by man directly, or indirectly (Dawson, 2003). It is the intention of this study to make a distinction between traditional technologies that employ whole organisms; for example, lactobacilli cultures to make yogurt and the new 'biotechnologies' which manipulate microbial genomes to manufacture products, most of which are not naturally produced by micro-organisms, for example, the industrial production of insulin. The main reason for this is because of the age of the children in this study. The traditional technologies that use micro-organisms associated with food production; for example, baking, brewing and preservation are those that children, especially the 11 and 14-year-olds involved in this research, might be expected to know about from school curricula. They might also be expected to have some ideas about medical applications; for example, in the production of vaccine and antibiotics. However, children within these age groups are not expected to learn about genetic engineering, or other biotechnologies and it would therefore be inappropriate to include these within this study.

2.9.1 Traditional technologies

Micro-organisms used to preserve, or enhance, the flavour of food or make new products, are ancient technologies. The Babylonians used yeast to make leavened bread and grape juice has been fermented into wine since biblical times. Yet pupils often seem to be unaware of these processes (Williams and Gillen, 1991). Simonneaux (2000) found that pupils were unfamiliar with the uses of bacteria, although examples from the food industry, such as cheese, bread and alcohol production, were the most commonly cited. However, some responses exhibited surprise that micro-organisms could be used to produce food, because of the negative connotations these pupils hold about bacteria. Microbial activity was thought to consist of bacteria attacking, or eating the food and, as a result, destroying part of it in order to make something else. This was particularly evident in discussion about yogurt production, where bacteria were seen as decomposing the milk, letting it go off, or curdle, *'the bacteria attack the organic matter in milk, and so get rid of the organic matter in it'* (Simonneaux, 2000:632). However, the manufacture of yogurt was not seen as a deliberate process and fermentation was a case of simply allowing the milk to change because the bacteria were already there in the milk, or they had just come from the surrounding environment. The pupils also showed confusion about the type of micro-organisms used in food manufacture; for example, in the production of cheese, bacteria and fungus are considered to be the same thing, *' bacteria... its like fungus actually.... Because there's a mini fungus which is dust'* (Simonneaux, 2000:632). This may of course be due to the production of cheeses, which have obvious fungal growth; for example, Stilton or Roquefort.

Pupils were not able to describe many other industrial processes using micro-organisms; for example, antibiotic or vaccine production, even though their use was explored in the interviews. Responses tended to relate to protection from infection, or to cure a disease (Simonneaux, 1996). Although some pupils suggested that vaccines were related to the diseases, or to the micro-organisms which cause them, and a few pupils in the study by Maxted (1984) suggested that bacteria would be useful when dead for making medicines or vaccines.

The production of silage, as a use for bacteria, a familiar process for the agricultural students in Simonneaux's study, was acknowledged by most of the pupils (Simonneaux, 2000). The bacteria were thought to destroy, or attack the organic matter in order to decompose it. This is consistent with the idea of bacteria being aggressive and attacking or feeding on food or human hosts. Little was understood about sewage plants and some pupils regarded decomposition as a negative consequence of microbial activity and Leach *et al.* (1996) observed that few children of any age in their study mentioned composting. The beneficial aspects of decomposition, either in industrial use, or domestic gardens do not seem to be well recognized.

2.9.2 Biotechnology

Recent studies to determine secondary-aged pupils' understanding of biotechnology indicate that many do not know what biotechnology is and half are unable to give a specific example (Lock and Miles, 1993; Lewis *et al.*, 1997; Chen and Raffen, 1999; Dawson, 2003). Lock and Miles (1993) noted that genetic engineering was more likely to be approved of when it concerned micro-organisms, rather than animals. This may be due to the question these pupils were asked, concerning the efficient treatment of human sewage, which they probably thought to be a very worthwhile thing to happen. Consideration about the genetic manipulation of micro-organisms was therefore not the most important factor in answering this question. It may also be due to a lack of concern in terms of micro-organisms, as they are not regarded in the same way as animals. It is worth noting that Lock *et al.* (1995) and Dawson (2003) found that after teaching sequences, not only did knowledge increase, but also attitudes towards new technologies became more favourable.

The lack of understanding of the technological potential of micro-organisms in both traditional technologies and biotechnologies is worthy of note. It is important that children have the opportunity to develop their ideas, based within traditional technological use of micro-organisms, before they are introduced to more complex ideas.

2.10 What are micro-organisms? A scientifically accepted view

The following section is a résumé adapted from Woese *et al.* (1990), Madigan, Martinko and Parker (2003) and Black (2005), and summarises the current knowledge and understanding of micro-organisms that is scientifically accepted, and with which I concur. The résumé provides information in respect of the seven themes identified from the literature review.

2.10.1 Classification

The classification of micro-organisms has been hotly debated for many years; Bissett (1963) suggested that bacteria should belong to a separate Kingdom. More recently Woese et al. (1990) introduced the notion of a phylogenetic 'Family Tree', based upon RNA and DNA sequencing techniques, in which there are three domains: bacteria and achaebacteria being ascribed to two of those domains, with all eukaryotic organisms belonging to the third. Rather than five kingdoms, Woese's three domain view of life is now generally accepted by evolutionary biologists and microbiologists and is considered a more appropriate way of classifying living organisms compared to the more traditional five kingdoms found in many school textbooks.

This study considers children's ideas about three microbial groups, bacteria, viruses and fungi. In the traditional classification system, bacteria are part of the Monera in which all other prokaryotic organisms are placed. Fungi have a separate kingdom, but in the three domain system they are regarded as evolutionarily closer to plants than the five kingdom system might suggest. Viruses pose an interesting problem in classification terms, as they cannot be truly considered to be living in the same way as bacteria and fungi. Viruses, therefore, do not 'fit' into any taxonomic group and are considered as separate entities by taxonomists. The taxonomic details of modern biological classification systems may not be of major relevance to primary and early secondary school science; nevertheless, children should have the opportunity to develop their understanding of how micro-organisms are classified. From a constructivist perspective, meaningful learning occurs when concepts are assimilated into an individual's schema or mental model and the learner makes connections between more generalized and specialized concepts in a process called subsumption of concepts (Ausubel, 1968). Therefore, understanding how micro-organisms are classified may lead to an understanding of how they are related to other living things, their place within ecosystems, as well as their morphology, size, and physiology. It follows that, within a constructivist framework of learning, it is essential to consider how children classify bacteria, viruses and fungi. The constructivist view of learning is dealt with more fully in Chapter 3. Knowledge and understanding of classification is important not only to help children make sense of the world in which they live but also because:

- the concepts 'living', 'animal' or 'plant' are fundamental and form the core to biological theory;
- understanding these basic concepts form the precursors to understanding more sophisticated classification systems;
- the concepts form the basis for more complex ideas such as variation, biodiversity, interdependence, genetics and underpin much of the work in ecology.

2.10.2 Morphology

Micro-organisms include the fungi, protoctista (algae and protozoa), bacteria, archaebacteria and viruses. Bacteria and achaebacteria are prokaryotic cells, i.e. they do not have a defined nucleus or other cell organelles. Algae, protozoa and fungi have a eukaryotic cell structure like all multi-cellular organisms. These micro-organisms are distinct from multi-cellular organisms in that a single cell can live alone and carry out its life processes, whereas the cells of a plant or animal can only exist as part of the whole organism.

Viruses do not have a cellular structure; they have a protein coat, which contains either a strand of DNA or RNA. Although they contain their own genes, they do not contain any other cellular apparatus and rely on a host cell for protein synthesis; they are therefore obligate parasites.

2.10.3 The living and non-living state

Bacteria and fungi are living organisms, they are dynamic open systems that take in nutrients and expel waste products. However, viruses do not, they are quite stable and only when a virus infects a cell does it acquire the key attribute of a living organism, that of reproduction. As such, they can be thought of as living, albeit in a different manner from other organisms.

2.10.4 Size and scale

The term micro-organism means those living organisms that cannot be seen with the naked eye; in other words they are microscopic. The size of micro-organisms ranges from 1-5 micrometers for a typical bacterium (a micrometre is 1 millionth of 1 metre), 65 nanometers for a virus particle (a nanometre is 1 thousandth of 1 micrometre), to 250 micrometres for a protozoan like *Paramecium*.

2.10.5 Disease, health and infection control

Some micro-organisms are the agents of disease and these aspects of microbial activity were the main areas of research for microbiologists and arguably, rightly so. Before the twentieth century, almost 50% of children under 10 years old died of infectious diseases in the industrial West. However, most micro-organisms are not harmful and less than 1% of all micro-organisms are pathogenic. Indeed many micro-organisms assist in maintaining health and well being. For example, bacteria (and protozoa) in the gut of ruminants, such as sheep or cows, digest grass so that nutrients can be absorbed by the animal; or commensal bacteria found on human skin help to prevent colonisation by pathogenic organisms.

2.10.6 Ecology and ecosystems

The ubiquity of micro-organisms and the wide range of metabolic processes they can undertake make them the most important group of living organisms to the life of the planet. Quite simply, if micro-organisms did not exist, then neither would we, nor would life as we know it. Micro-organisms can be found everywhere. They are in the air we breathe, the food we eat and the clothes we wear. They can be found in the coldest seas and the hottest sulphur springs. Their ability to colonise virtually any habitat makes them the most widely distributed and diverse group of living organisms on the planet. These adaptations have played a major role in the evolution of life on Earth. Archaebacteria, that are able to exist in anaerobic conditions and produce energy by metabolising inorganic iron, are thought to be relatives of primitive organisms that produced energy autotrophically from a variety of inorganic compounds and are considered to be the origin of complex life forms. The oxidisation of the atmosphere about 3 billion years ago represents a milestone in the evolution of life on Earth and the oxygenic phototrophs, the cyanobacteria, are considered to be responsible for this.

Micro-organisms are responsible for unwanted decay, in the form of food spoilage and the deterioration of buildings; for example, fungal attack causing wet rot in wood. However, many microbial activities that might appear to be negative have a very valuable and positive aspect; without the decay of complex organic compounds, materials would be trapped in the bodies of large plants and animals and the biological cycles of the planet would have stopped millions of years ago.

Microbial metabolic processes are important in the cycling of nutrients such as carbon, nitrogen and sulphur. Microbial activity causes decay and putrefaction of complex organic compounds, converting them into inorganic substances; for example, carbon dioxide, which is used directly in photosynthesis by other organisms including plants. Other soil and water inhabiting micro-organisms render inorganic nitrogen and sulphur into forms that can be assimilated by plants.

2.10.7 Technological applications

Traditional food technologies, using micro-organisms such as the production of wine, leavened bread, yogurt and cheese, have been important to man for thousands of years. More recently, microbial activities and the products of their metabolism have been exploited to produce a wide range of food and other products industrially; for example, enzymes in biological washing powders, the production of fructose for soft drinks, stabilisers for ice-cream and the production of vitamins and antibiotics. Furthermore, some micro-organisms can decompose oil, solvents and other pollutants and are used to help clean up the environment in a process called bioremediation.

Increasingly, genetically modified micro-organisms are being employed as the tools in research and industry. These new biotechnologies insert the desired gene into micro-organisms where it can be expressed to make the desired gene product, for example, the human hormone insulin, used in the treatment of diabetes.

2.11 Science and language

We express and extend our thinking through using language: language enables ideas to be translated into symbolic form in our mind (Vygotsky, 1962; Bruner, 1964). Furthermore, using language enables a learner to re-order and re-interpret ideas and experiences and as such, language becomes a cognitive instrument. In addition, the role of language in supplying meaning to experiences is paramount to understanding (Ausubel, 1968). Language is, therefore, crucial to a child's cognitive development. These ideas are relevant to children's understanding of, and learning about, science.

When children are challenged to explore scientific ideas in school, they encounter language that differs from everyday language in the specialized semantics and terminology that is inherent in scientific idiom. Science has a particular code of communication and language used in a 'scientific' way often has specific meanings that are different from everyday language (Gilbert *et al.*, 1982; Watts and Gilbert, 1983; Bell and Freyberg, 1985; Driver *et al*, 1985a; Leach and Scott, 1995; Wellington and Osborne, 2001; Leach and Scott, 2002; Dawes, 2004). For example; a sign placed on a shop door saying 'no animals allowed' suggests that people are not animals, indicating an everyday usage of the term 'animal' that is different from a biological one (Bell and Barker, 1982). Therefore, the language used in science, by teachers or other adults, may not be accurately interpreted by children because it does not resonate with their everyday language. Conflicting interpretations can affect a child's understanding of school science, with regard to specific vocabulary, for example; understanding the causes of the common cold discussed in section 2.7.3, earlier in this chapter (Helman, 1978; Driver *et al.*, 1994). Such semantic differences can cause difficulties with regard to clear communication between teacher, or researcher, and the child. A child may express his or her ideas about a scientific phenomenon without using scientific language; for example, describing the immune response to microbial infection in anthropocentric terms. However, this does not necessarily mean a lack of understanding, or an inability to understand the scientific concepts. Indeed, Watts and Bentley (1994) go so far as to suggest that making use of children's animistic and anthropomorphic thoughts may help to make science more accessible to children. Conversely, a child may adopt and use scientific language without fully understanding it, or the concepts it conveys (Bell and Freyberg, 1985; Harlen, 2001). Taking account of these issues and exploring exactly what children mean when they are expressing ideas in science is important in enabling them to learn and make progress

Scientific discourse is not the same as ordinary talk; it is stylized. Children not only have to assimilate the use of specific terminology but also adjust to the way in which that terminology is used; they need to become 'encultured' into the community of practice (Tobin,1998). From this socio-constructivist perspective of learning science, Lemke (1990) and Leach and Scott (2002) suggest that learners need to be able to speak the language of science in order to make sense of what is going on in science classrooms. Vygotsky (1962) indicates that the use and development of language in social contexts is important in facilitating cognition. More recently, a number of authors have suggested that providing opportunities for children to develop scientific ideas through the medium of discourse; as exploratory talk, or, in applying argumentation, is beneficial to learning (Newton *et al.*, 1999; Dawes, 2004; Mercer *et al.*, 2004; Osborne *et al.*, 2004; Watson *et al.*, 2004; Simon *et al.*, 2006; Naylor *et al.*, 2007). Furthermore, Mercer *et al.* (2004); Osborne *et al.* (2004); Dawes, (2004) and Naylor *et al.* (2007) indicate that specific scientific concepts are understood more clearly, when children are engaged in productive science talk. Crucially they assert that children's way of thinking in science and their ability to make use of the structures, styles and conventions of scientific discourse, in other words their scientific literacy, is improved through such engagement.

I have endeavored to pay heed to these issues within the research that follows and the importance of language in interpreting children's ideas with regard to micro-organisms is acknowledged as an important aspect of research. However, further exploration of the particular use of language by children in expressing their ideas about micro-organisms, and considering ways of bridging the semantic gaps is beyond the scope of this study but would be an interesting extension of the work presented here.

2.12 Summary

It is difficult to draw any firm conclusions about children's ideas about micro-organisms from this review of literature because the work cited has taken place at different times, in different places, with different age groups and used different methodologies. The present study begins to address some of these differences by providing a more comprehensive study than has been previously undertaken. It endeavors to do this by considering children's ideas about micro-organisms across three specific age ranges using the same methodology. In doing so, it has attempted to show the pattern and progression of children's ideas about micro-organisms in the key conceptual themes discussed in this chapter.

However, the literature has provided a foundation upon which to build the research presented here; in particular, what ideas are currently held about micro-organisms by children in England, what ideas are commonly held by all age groups, what concepts seem to be difficult to comprehend and how children's ideas develop with age.

Chapter 3

Theoretical framework and research design

3.1 Introduction

According to Mertens (1998) and Cohen *et al.* (2007), what distinguishes research from other forms of searching for 'truth' are the systematic, empirical, and self-correcting dimensions of the process. Research, unlike reasoning, or experience, attempts to take into account all the evidence, to scrutinise that evidence in a critical manner, in order to uncover the answers to particular problems or questions. Many others offer similar thoughts in their definitions. For example, Kerlinger (1983:11), *'systematic, controlled, empirical and critical investigation of hypothetical propositions about the presumed relations among natural phenomena'; or* Bassey (1995:2), *'systematic, critical and self-critical inquiry which aims to contribute to the advancement of knowledge'* and Kumar (1996:7), *'it [research] must, as far as possible, be controlled, rigorous, systematic, valid and verifiable, empirical and critical'.* Wellington (1996) makes the point that it is the critical and self-critical stance that researchers adopt that is of paramount importance, because it implies that data collected are closely scrutinised and that methods, analysis, interpretation and presentation of findings are also subject to similar scrutiny, thus offering conditions in which researchers can have confidence that their findings are valid and reliable. Whilst Verma and Mallick (1999) regard these definitions more applicable to the natural rather than the social world, nevertheless, they agree, what epitomises research is the systematic and rigorous approach taken in the search for trustworthy and meaningful knowledge.

So that the research questions are answered with confidence, the overarching theoretical framework that informs the research design and methodology must be carefully considered (Dawson, 2002).

This chapter discusses the theoretical framework that guides this research, it establishes the paradigm in which the research is located, discusses the overall research design and the methodology that has been adopted and the ethical issues that were taken into account. It concludes by putting the research into context by providing a brief description of the location where the study took place and the participants that took part in the research and includes a discussion of the curriculum content that they will have studied.

3.2 The theoretical framework

This study explores children's ideas about micro-organisms across three age groups. I consider that, whether children have been formally taught about micro-organisms, or not, they will have some ideas about them, and that the ideas children hold are legitimate. Thus, the research is located within the constructivist view of learning science.

Constructivism holds that new learning and knowledge acquisition relies upon learners actively engaging in the construction of knowledge for themselves, either individually, or in a social context, rather than as, 'ready made' entities handed to the learner for passive assimilation. It is also an established premise within science education that children have ideas based upon prior experience and that these ideas may, or may not, be in accord with the orthodox scientific view (e.g. Driver and Easley, 1978; Gilbert *et al.*, 1982; Watts, 1982; Osborne and Freyberg, 1985; Driver,1989; Shepardson, 2002). Furthermore, these alternative ideas are resistant to change because they have relevance and meaning for the child. These views are fundamental to the constructivist approach to learning science. It is this framework of ideas that underpins the research presented here.

3.2.1. Constructivism and learning

The foundations of constructivism and its view of learning can be found in the work of theorists such as Piaget (1929); Vygotsky (1962); Ausubel (1968) and Kelly (1995). It is not a homogenous concept and learning is thought to be constructed in a variety of ways. Piaget (1929) proposed that learning occurs through an individual's physical and mental engagement with the environment and that cognition is dependent upon developmental stages. Driver (1993) acknowledges that Piaget's research into the way children learn by reacting with their environment has been a fundamental influence on the development of constructivism. However, there has been a great deal of criticism of Piaget's stages of learning for being too deterministic (Brown and Desforges, 1977; Driver and Easley, 1978; Novak, 1978), although Selley (1999) suggests, much of this criticism has been due to the over-simplification and misinterpretation of Piaget's ideas, a point made earlier by Driver and Easley (1978). However, Piaget's view of learning is seen as process driven and independent of content, requiring logical structures and operations that are age-dependent. In contrast, Ausubel (1968) considers learning to be content driven, and that meaningful learning requires the structuring (and restructuring) of specific concepts that are related to existing concepts in the learner's cognitive structure, suggesting a dynamic to-ing and fro-ing of ideas. Thus, new ideas become assimilated into an existing schema or mental model, where links are made between them and existing ideas, thereby enlarging and sophisticating the learner's mental model. A more structured view of learning is presented by Vygotsky's (1962) 'zone of proximal development', which suggests that the learner acquires knowledge by systematically enlarging and expanding their knowledge base. Vygotsky goes on to state that learning is more likely, and is more effective if the new knowledge is within the compass of related ideas held by the learner, which has echoes of Piaget's notion of 'moderate novelty'. Kelly (1955) expands on the idea that learning is a dynamic process actively involving the learner and suggests that knowledge is created by individuals constructing tentative models, which are then evaluated in terms of their predictive power and control of events. This is described by von Glasersfeld (1989) as a revision of conceptual schemes in the light of their 'fit' with experience. Driver (1989:482) sums up these views by saying that the constructivist view of learning *'...is seen as an adaptive process, one in which the learner's conceptual schemes are progressively reconstructed so that they are in keeping with a continually wider range of experiences and ideas'.*

In addition to the focus on domain specific knowledge structures, social interactions at an individual level and within communities have an important position in the constructivist view of learning (Tobin, 1998). Knowledge is gained not only through observations, which are regarded as theory-laden (Kuhn 1962), but through social processes which involve conjecture in which, *'argument is used to construct plausible links between the imaginative conjectures of scientists and the available evidence'* (Newton *et al.*, 1999:555). Knowledge gain is, then, the result of a discourse, which aims to determine which conjectures provide the most convincing explanations. Kelly (1955); Vygotsky (1962) and Solomon (1987) consider that language and other forms of communication direct and mediate knowledge construction. From this socio-linguistic perspective learning occurs through talk, writing and thinking through explanations of scientific phenomena (Driver *et al.*, 1994), which requires active participation of the learner in the discourse of lessons (Newton *et.al.*, 1999; Osborne *et al.*, 2004; Simon *et al.*, 2006). Learning, therefore, includes both a personal construction and a socially negotiated meaning (Shepardson, 2002).

3.2.2 Children's ideas in science

Constructivism is an epistemological theory concerned with the structure and process of learning (Bentley, 1998) and it holds that every individual constructs their own ideas rather than receiving them complete, whole and accurate from a source of authority (Selley, 1999). From this perspective, learners are not regarded as the passive recipients of knowledge (jugs waiting to be filled up), but as active participants in the learning process (Bentley, 1998). Their viewpoints need to be taken into account and should affect the teaching and learning dialogue (Whitelock, 1991). Learners in science employ a shared language, which enables them to communicate and test the ideas they hold against those held by others, when a consensus or 'fit' is reached within the group, personal constructions become similar to those of others with whom the discourse has taken place (Tobin, 1998). However, as Tobin points out this could serve to obscure meaningful learning and increase the likelihood of initial conceptualizations being retained. The role of the knower, with regard to children's learning is therefore of paramount importance and in a school context is most likely, but not exclusively the teacher, in mediating this learning process.

Discovering the ideas that children hold about particular scientific concepts is now considered to be an important aspect of a constructivist approach to learning. The work of Osborne and Freyberg (1985) and Driver *et al.* (1985a) gave new and continued impetus to this field of research. The research described here is part of that tradition and aims to contribute to the substantial body of knowledge that already exists. That children acquire ideas, in trying to make sense of scientific phenomena, from a variety of sources, including everyday events and situations, is an established premise of a constructivist view of learning. It is, therefore, not surprising to find that the ideas children have about many scientific phenomena differ from the accepted view. Children's ideas about many scientific concepts and the alternative ideas they have, in different areas of science, have been well documented (e.g. Osborne and Freyberg, 1985; Russell and Watt, 1990; Osborne *et al.*, 1992; Driver *et al.*, 1994). These ideas have been variously referred to as, quaint distortions (Piaget, 1929); alternative conceptions (Driver and Easley,1978);

misconceptions (Za'rour, 1976; Helm, 1980); naïve alternative framework/preconception (Nussbaum and Novick, 1981); children's science (Gilbert *et al.*, 1982); alternative frameworks (Watts, 1982) and novice belief systems (Carey, 1985). The terminology, as Whitelock (1991) and Driver (1993) note, depends upon the context and theoretical background of the researcher. As Driver and Easley (1978) elaborate, the term misconception is often applied in connection with nomothetic studies in which children's ideas are assessed in terms of their congruence with accepted scientific ideas and have the connotation of being wrong. On the other hand, alternative frameworks describe the intuitive ideas children hold as a result of attempting to interpret the world about them, and studies which attempt to discover these ideas, are considered as ideographic. Whilst an expert overview of micro-organisms is used as a framework of reference, it is the latter ideographic view rather than the former nomothetic view of children's ideas and the subsequent implications for teaching and learning about micro-organisms that concerns this study.

3.2.3 Conceptual change

Conceptual changes are thought to occur when a functional level of cognitive dissonance is present between existing ideas and new ones (Driver, 1993). However, di Sessa (1988) argues that in order to move to a recognised view of science the learner needs to construct a new and profound systematic framework, which cannot be obtained through the cognitive conflict induced by the juxtaposition of alternative and scientifically accepted ideas. Carey (1985) suggests a more complex view of conceptual change and considers that ideas can change at two levels. A weak restructuring of ideas occurs when new facts are accumulated and the individual gains expertise. However, true conceptual change only occurs when strong restructuring takes place. Strong restructuring creates the establishment of a new conceptual structure in which the meaning of the individual concepts have changed and more complex relationships exist between them and the domains of the phenomena it explains; resulting in the creation of new schemata. Carey considers that strong restructuring of ideas involves conceptual reorganisation and amounts to a fully fledged theory change. However, subtleties about the nature of conceptual change have given rise to the notion of the degree of restructuring required for different concepts and for different ages (Hogan and Fisherkeller, 1996).

Clearly, the process of conceptual change is not straightforward. Particular ideas may take several years to evolve, with a variety of incomplete, or alternative, frameworks being held, before an accepted scientific idea is reached (Driver and Erickson, 1983; Driver *et al.*, 1985b; Engel Clough *et al.*, 1987; Driver, 1989; Cuthbert, 2000; Harlen, 2000). Carey (1985) and Osborne *et al.* (1992) consider that it is not until the age of about ten years that children's biological knowledge develops and their ideas become more closely aligned to accepted knowledge frameworks. As Gilbert *et al.* (1982) and Driver *et al.* (1985b) explain, the ideas children hold are based upon reasoning; and this reasoning makes sense to them, making the ideas resistant to change. A point made by Ausubel (1968), when discussing what he called preconceptions, is that children's ideas are stubbornly held and very difficult to change. According to Driver *et al.* (1985b) children will also hold on to alternative ideas, contemporaneously with accepted scientific views; something Driver (1989) describes as situated cognition. Novak (2002) adds that when meaningful learning is absent, learners have difficulty in transferring knowledge from one context to another, and that knowledge remains 'situated' in the original learning context. Indeed, Whitelock (1991) suggests that pupils can compartmentalise their knowledge and accommodate school science as something divorced from the real world without any dissonance. However, Solomon (1983) suggests that it is not so much a matter of learners changing their conceptions, but more of their ability to distinguish between different contexts and apply conceptions appropriately. Von Glasersfeld (1996) takes an extreme perspective. His notion of radical constructivism suggests that an external reality may exist, but the learner does not have direct access to it. The learner therefore creates his or her own reality, which offers them a personal logic to describe phenomena.

Strike and Posner (1982) suggest the conditions must be right if conceptual change is to occur, and they have proposed several criteria that are pre-requisites to conceptual change. They suggest it is highly probable that any restructuring is likely to be temporary or not occur at all if children are not unhappy with their own ideas (dissatisfaction), the ideas presented to children do not make sense to them (intelligibility), are not believable (plausibility),nor have the potential for further learning (fruitfulness). Strike and Posner's pre-requisites offer a set of conditions that provide fertile ground for conceptual change however that is achieved. Pintrich, Marx and Boyle (1993) consider that, in addition to the pre-requisites suggested by Strike and Posner (1982), the motivational beliefs of the learner, such as goals and self-efficacy also affect conceptual change. Their view of 'hot cognition' proposes that motivational and social factors interact with the previous four conditions in affecting the nature of any conceptual change.

3.2.4 Mental models

The study of mental models has increased in science education as a way of helping to understand the process of learning and, in particular, the representational nature of knowledge (Greca and Moreira, 2000). Gilbert and Boulter (1998:92) define a model as representations of *'ideas, objects, events, systems or processes'*. Mental models are considered as the personal ideas, or internal representations of individuals about particular concepts and their knowledge of the world (Duit and Glynn, 1996; Greca and Moreira, 2000), although they are not thought to be static entities. Johnson-Laird (1983) considers that mental models are dynamic representations; that they are never complete and continue to enlarge and improve as new information is added to it. Meaningful learning is thought to occur when knowledge is assimilated into a person's mental model and connections are made to strengthen and deepen his or her conceptual understanding. A mental model can, therefore, provide an indication of what an individual understands about a concept at a particular point in time and includes their knowledge of, as well as his or her beliefs about the concept. Attempting to define the mental models children hold, at different ages, about micro-organisms, will begin to identify the nature of children's understanding, as well as helping to develop a view of the progression of their ideas across the three age groups presented in this study.

3.3 Research paradigms and approaches

All research attempts to impart new knowledge, or a novel facet to existing knowledge, in order to promote deeper understanding and enlighten thinking. It is considered to be an active pursuit of knowledge and can take many forms. Different intellectual traditions exist that contain alternative underlying assumptions about how the social (and natural world) operates and that offer diametrically opposing views and ways of thinking about how to seek out trustworthy and meaningful knowledge (Wellington, 1996). These constructions of social reality, or paradigms, form a loosely connected group of ideas, questions, methods, and procedures and give direction to research, offering a set of rules or dispositions that guide everyday practice (Bogdan and Biklen, 1982; Popkewitz, 1984; Lincoln and Guba, 2000).

The normative, or empirical-analytical, and the interpretive, or symbolic, are considered to be the traditional approaches to educational research (Cohen *et al.* 2007) and, at their extremes, represent a dichotomy in views about the social world. The normative research paradigm considers that the social sciences are, in essence, the same as the natural sciences. Wellington (1996) describes the normative paradigm as a perception in which an external objective reality exists which is independent of the observer and states that the aim of normative research is to seek generalisations and hard, quantitative data. It follows that the process of enquiry involves scientific methods, such as experiments and surveys, and that theory forms the starting point of this type of research. The scientific method was widely adopted by researchers and came to be the dominant approach within educational research. Indeed, proponents of normative research have suggested that it is superior to other forms of enquiry because of its rigour, reliance on scientific method and production of quantitative verifiable data (Campbell and Stanley, 1963; Kerlinger, 1983).

In contrast, the interpretive research paradigm considers that reality is a human construct and is created by an individual's interpretation of his or her interaction with the world (Cohen *et al.*, 2007; Denzin and Lincoln, 2000). It is, therefore, time and context dependent. Interpretive researchers accept that they will make a difference to the observed phenomenon, as they attempt to make sense of phenomena in terms of the meanings people bring to them (Denzin and Lincoln 2000). The aim of interpretive research is, as Cohen *et al.* (2007:21) state, *'to understand the subjective world of human experience'.* Qualitative data are produced through methods such as case study, interviews and observations, in which the particular reality of the individual is recognised rather than the general rules produced by normative research methods. Whilst theory is developed as a result of research data, it is a product of the research rather than preceding and guiding it. In other words, it is, 'grounded', in the research (Lincoln and Guba, 1985; Robson, 1993). Some (Campbell and Stanley, 1963) would argue, therefore, that this type of research is not scientific, although others (Bogdan and Biklen, 1982; Lincoln and Guba, 1985; Cohen *et al.*, 2007) suggest that all forms of systematic research are, 'scientific', in nature.

However, the apparent clear-cut distinctions between qualitative and quantitative research are less obvious than much of the literature seems to suggest. Bryman (1988) makes the point that many of the distinctions are in the minds of theorists and philosophers and that in practice these distinctions may become blurred. In fact these extreme views are not helpful and can deflect much of a researcher's energies. As Wellington (1996) suggests, researchers in education should aspire to making their research systematic and trustworthy, rather than engaging in fruitless debates about 'scientific' or 'non-scientific' research. A key factor to consider is that there are different ways of regarding social reality. Rather than one being right, or superior to the others, all views can contribute to a fuller understanding by providing interpretations of the same phenomenon from different perspectives, thereby enriching comprehension rather than diminishing it. By endeavouring to select methods and approaches that are appropriate to the issue being investigated, rather than strict adherence to one or other extreme viewpoint, reality is seen through different lenses, adding colour, depth and vibrancy to the issue. Indeed, this is regarded as a strength of research by many authors (e.g. Popkewitz, 1984; Wellington, 1996; Verma and Mallick, 1999; Denzin and Lincoln, 2003) and that is the position adopted within this research. As Thomas (1998:5) comments:

> In my opinion the typical qualitative versus quantitative argument is ill conceived. The proper issue is not whether one of these approaches is generally superior to the other. Instead, the issue is: what circumstances determine which of these approaches will be the most appropriate? Oftentimes both qualitative and quantitative information is desired.

The research presented here is an interpretive study, although there are elements that could be regarded as belonging to the normative paradigm. It employs a survey strategy to seek generalisations about a population's ideas. It adopts a systematic 'scientific' approach by attempting, within the context of different schools and classrooms, to maintain the same conditions for each subject. However, for several reasons the research most comfortably sits within the interpretive paradigm (Cohen *et al.*, 2007) or, as Denzin and Lincoln (2000) would distinguish, the constructivist paradigm or approach, within qualitative research. The research sets out to discover what children know about micro-organisms and is primarily concerned with collecting qualitative data. The research interprets children's ideas, rather than measuring them or comparing them to an objective framework. With this in mind, the currently scientifically accepted view of micro-organisms was used to interpret the data and was employed as a guide, rather than an imperative instrument. Data were interpreted and categorised rather than being considered as correct, or not, and theory was allowed to emerge from the data, rather than being subjected to an analytical framework. As such, the research assumed a relativist ontology that accepts that there are multiple realities; in this case, that children may have many different ideas about micro-organisms. Furthermore, the research adopted a subjectivist epistemology; interpretation of children's ideas was to some extent a joint process, in which the children and I co-created meaning. Finally, the research was conducted in as naturalistic a setting as possible, the children's normal classrooms were used and as far as possible activities that were familiar to the children were employed as research instruments.

3.4 Research design

The notion that research is a linear logical process is challenged by Wellington (1996) whilst Medawar (1963) goes further and suggests that this portrayal of research is a fraud with the reality being much more a mixture of conjecture and reassessment. Brymann and Burgess (1994) concur; they believe that research is not a clear-cut process of a sequential set of procedures, but a dynamic process in which theories and methods are linked. However, such views could suggest that research is, to some extent, random and arbitrary and that any attempts to plan or design a research project are not worthwhile. Whilst this is a radical interpretation, Denzin and Lincoln (2003) argue that, although the research design is a flexible set of guidelines, it provides an overarching framework that connects theoretical paradigms, first to strategies of enquiry and second to methods of collecting empirical data. Bryman and Burgess (1994) elaborate their point, by suggesting that in designing a project, establishing a way forward that will answer the research questions is of vital importance to the success of the project. Robson (1993:38) says, *'design is concerned with turning research questions into research projects'*, and the key issue in design is to employ the most appropriate strategy and methods to address the questions effectively (Bell, 1993; Robson, 1993; Cohen *et al.*, 2007; Denzin and Lincoln, 2003). As Kerlinger (1969) points out, the outcome will be flawed, if the research design is not well constructed.

A well-designed project in which the theoretical and methodological issues are considered is, therefore, critical to the success of the project. A survey strategy is considered to be a suitable design for this research, although clear departures from a classical survey are evident. Denzin and Lincoln (2003:24) describe such a departure as *'the moment of blurred genres'*, in which the researcher borrows ideas and methods from different traditions. Robson (1993) describes a study such as this as a hybrid study, where one strategy is subsumed into another, and compares them to combined studies, where one strategy is used sequentially after another. This study brings together two differing traditions; the normative and interpretive, and makes something new, therefore, the term 'hybrid' seems to most accurately reflect the design of this study.

The research presented here is a cross-sectional study, employing multiple methods (Robson, 1993; Verma and Mallick, 1999; Cohen *et al.*, 2007) which collect qualitative data. A range of methods suitable for the age range of the participants was sought that avoided the younger children becoming overwhelmed, or confused, whilst ensuring the older children did not feel patronised. In addition, the multi-method approach, or triangulation, allows respondents to provide information from a variety of standpoints, adding to the richness, depth and vibrancy of the data (Denzin and Lincoln 2003) and allows corroboration of findings, which can give some indication of the validity of the responses (Cohen *et al.*, 2007). Cohen *et al.* go on to argue that a further benefit of triangulation is that it prevents researchers from only using those approaches that they prefer, or are familiar with and prevents them from becoming, 'methodologically bound'. A variety of techniques were used during the administration of each method. Instrumentation was trialled and modified in the light of a pilot study. A plan of the research design, adapted from Cohen *et al.* (2007) is shown in Figure 3.1.

The six phases identified within the overall design are:

Phase 1	Pilot study;
Phase 2	Planning and refining research instruments in the light of the pilot study;
Phase 3	Sampling and selection of schools, and children;
Phase 4	Elicitation of children's ideas about micro-organisms;
Phase 5	Initial analysis of data to select up to a 10% sample for follow up interviews;
Phase 6	Elicitation of children's ideas via follow-up interviews.

The overall design indicates that data were collected from a variety of children, employing different techniques at different times and were designed to elicit children's ideas about micro-organisms from a range of perspectives. These were administered to a representative sample of children at ages 7, 11 and 14 years respectively. A smaller number from the initial sample was followed up, within approximately two weeks of the initial data collection, using a largely structured one-to-one interview. A full discussion of the methods and techniques and the subsequent analysis of data used during the research can be found in Chapter 4.

Figure 3.1
Research design used in this study (after Cohen *et al.*, 2007)

Phase 1	*Phase 2*	*Phase 3*	*Phase 4*	*Phase 5*	*Phase 6*
Pilot study	Analysis of pilot study findings Planning and refining research instruments as a result of pilot study	Sampling selection	Main data collection: - drawings - brainstorms - concept maps	Selection of interviewees	Interviews
June-July 2002	Sept-Dec 2002	April- May 2003	June 2003	June-July 2003	July 2003

3.5 Methodology

The Shorter Oxford English Dictionary (Onions, 1988) defines methodology as the 'science of method'. Methodology is, therefore, the process of surveying and choosing research methods, reflecting on the chosen methods and justifying the choice by evaluating their efficacy (Wellington, 1996). Methodology is an integral part of the research process; as Walker (1985) indicates, the methods chosen for the research are to be tested, just as much as the substantive hypothesis. Burgess (1984) goes on to suggest that methodology is not merely a technicality, but should include a consideration of the ways in which techniques, theories and processes are developed by the researcher in relation to the experience of collecting, analysing and reporting data.

This study is an exploration of children's ideas about micro-organisms and, rather like an explorer, the researcher was eager to discover what, 'lay out there', rather than looking for, 'what should be there'. According to Denscombe (1998) the research is highly suited to a survey, as it allows the researcher to discover the state of affairs about a particular phenomenon at a given point in time and this has been adopted as the overarching methodology for the research presented here. However, unlike traditional surveys, this project has employed multiple methods, which produced mainly qualitative, rather than embracing a single methodological set of processes, which would hinder the riches to be discovered (Denzin and Lincoln, 2000; Thomas and James, 2006).

An interpretive approach has been adopted that does not set out to test a hypothesis, but enables theory to emerge from the data (Glaser, 1992). Grounded theory, defined by Glaser and Strauss (1967), consists of a particular set of analytical strategies that move towards the refinement of data to enable connections and relationships between concepts to develop. As a result, theoretical frameworks can be built that explain the collected data (Charmaz, 2003). The aim of the research presented here is to explore children's ideas about micro-organisms and to develop theoretical models and typologies that represent those ideas. In doing so, it aims to induce a theoretical perspective about children's ideas about micro-organisms from the data, rather than deduce it from an existing analytical framework or theory. Therefore, the research is concerned with theory development rather than theory confirmation and can be regarded as 'grounded' (Denzin and Lincoln, 2003).

Charmaz (2003) states grounded theory is concerned with analytical strategies rather than data collection methods. She goes on to suggest that whilst grounded theory studies have tended to be limited to interview methods, they can and have been used with other data collection methods and that is the approach taken here. Furthermore, it is acknowledged that certain steps within grounded theory methodology have not been adhered to, such as accessing the literature as it becomes relevant, or employing saturated sampling techniques. Charmaz (2003) suggests that grounded theory methods should be used flexibly rather than as a set of formulaic procedures. With this in mind, analysis of the data in this study has espoused aspects of grounded theory, without necessarily following all of the procedures exactly. Data from the initial methods; the drawings, brainstorms and concept maps, described fully in Chapter 4, were subjected to open coding after a period of constant comparison, subcategories were developed and further exploration of the data enabled core categories to emerge (Glaser and Strauss, 1967; Strauss and Corbin, 1998). The core categories were subsequently used to identify connections and themes within the interview data. In this way, theoretical categories were developed from the data and were used to explain the data they subsume (Glaser 1992).

3.5.1 Surveys and survey methodology

Robson (1993) and Denscombe (1998) consider that surveys are more akin to a research strategy or methodology than a single discrete research method and that, within the survey strategy; many different methods can be applied. Indeed many surveys are multi-faceted and it is this viewpoint that the research described here has taken. In this case, a framework of a survey design has been used as an umbrella to incorporate the research instruments employed to obtain children's ideas about micro-organisms, on different occasions, using four distinct methods.

According to Verma and Mallick (1999), surveys are one of the most commonly used strategies in descriptive educational research and are well suited to studies, such as this one, where the aim is to discover how children's ideas about micro-organisms alter with age. Surveys are often regarded as a means of gathering standardized information from relatively large specific populations (Borg and Gall, 1983), although small-scale survey research is common in educational settings (Robson, 1993). A survey can indicate prevailing conditions, or particular trends, at a particular point in time and provides a comprehensive picture of the research focus by collecting and analysing empirical evidence, allowing a generalized picture to be formulated (Bryman, 1988; Robson, 1993; Denscombe, 1998; Mertens, 1998; Verma and Mallick, 1999; Cohen *et al.*, 2007). The research described here aims to discover the nature of children's ideas about micro-organisms across a defined age range, at a particular point in time; it is therefore particularly suited to survey methodology.

Two different approaches are frequently employed to study how characteristics in a population alter with age. A longitudinal method studies the same sample of people at intervals and a cross-sectional method, which attempts to study samples of people at different ages. Longitudinal studies are considered to be a most effective design in studying children's development over time because they are intensive and can gather information from a large sample (Verma and Mallick 1999). Major research findings, which have been and still are highly relevant, have been conducted in this manner; for example the impact of social class on an individual's development (Newson and Newson, 1965; 1970; 1978), or the effect of different schools for pupils (Rutter *et al.*, 1979). However, such studies require a great deal of time, and are highly cost and resource dependent. Whilst it is important to maintain rigour when planning a study, pragmatism is also a necessary element. Cross-sectional studies have the advantages of being less expensive and less time consuming and they do not suffer from sample mortality in the same way as longitudinal studies (Verma and Mallick, 1999). Taking these issues into account, a cross-sectional survey design was considered particularly suitable to address the research aims of this study.

3.5.2 Research methods and instruments

The purpose of a research method, or instrument, is to be used as a tool by the researcher to collect the data required to answer the research questions. According to Kumar (1996), the research instrument is the most important aspect of a research project, because any data collected and hence, any findings, or conclusions are entirely dependent upon the research instrument. If the research instrument is not an appropriate mechanism to collect the data required, or does not address the research questions, the quality and validity of the findings are in jeopardy. Kumar continues, saying that validity of the instrument(s) is determined by ensuring that the objectives of the study are achieved. It follows that clear objectives, or research questions, are required to facilitate the construction of the research instruments and to maintain the research focus (Lankshear and Knobel, 2004). The research questions in this study have been clearly identified and are stated in section 1.2 in Chapter 1, and provide the focus for the aims of this project; to discover children's knowledge and understanding of micro-organisms at different ages and what, if any, changes occur in their thinking with age. A full description of the research methods employed in this study can be found in Chapter 4.

3.6 Ethical issues

Research with human participants requires careful consideration of the ethical and moral issues that can arise as a result of engaging in the research (Cohen *et al.*, 2007). Deliberating these issues and ensuring that every effort is made to treat the participants and the information they provide with consideration and respect forms the basis of the ethics of research (Christians, 2000; Dawson, 2002). The ethical principles that were adhered to when planning and conducting this research were maintained in accordance with the British Educational Research Association's ethical guidelines (BERA 1992) and guidelines offered by other sources (e.g. Osborne and Freyberg, 1985; Bell, 1993; Robson, 1993; McNamara, 1994; Verma and Mallick, 1999; Cohen *et al.*, 2007; Dawson, 2002) and the procedures adopted are described below.

3.6.1 The research project

One of the first questions to consider is whether the benefits of the research outweigh any possible harm to participants as a result of conducting the research (Cohen *et al.*, 2007). The research was planned to discover children's ideas about micro-organisms across three age groups, with the intention of adding to the corpus of knowledge about children's ideas in science and about how ideas develop with age. The findings may help to inform the thinking of curriculum developers to encourage them to emphasize the place of microbiology within the curriculum. The findings could be used to improve the design of teaching and learning sequences about micro-organisms that will benefit learners.

In addition, satisfaction in taking part in the research, by providing information and by becoming more personally interested in the research focus, is considered a benefit. This was indeed evident to me during the data collection stages. Children were keen to take part and there was considerable disappointment that only a selected sample would be interviewed. However, the perceived benefits had to be considered against potential harm to participants, with this in mind, the research questions, the research instruments, field work and the final report were all considered. The latter two are dealt with separately below.

The research questions were framed in such a way that they would address the research issues without identifying individuals, or embarrassing them in any way. The research tools were designed to be appropriate for all age groups, so that anyone could take part fully without feeling disenfranchised or patronised. The content of the research tools was considered carefully and in most cases depersonalized, whilst potentially sensitive issues; for example, personal illness and recovery were treated with care and consideration for the individual being interviewed. It was for these reasons that the common cold, a microbial disease that children will have experienced, and which is unlikely to cause embarrassment, was chosen as an example of microbial illness to begin the questioning during interviews about health and disease.

3.6.2 The research field work

Several important principles were adhered to during the field work. The purpose and nature of the research and data collection methods were made overt to potential participants. This was achieved, in the first instance, by discussing with the headteacher of each school, the proposed research and the planned data collection methods. The nature of the research was described and each research method was explained. Prior to administering the data collection methods, I introduced myself to the children and explained what the research entailed, what methods were being used, and prior to each task, clear explanations were given, alongside a reassurance that every response would be accepted and that no response would be regarded as wrong. I agreed with the headteachers and the children participating in the research to maintain the anonymity of each school and each participant in any discussion with colleagues and in any subsequent written accounts whether they were published or not.

By attending to these preliminary principles I was in a position to seek informed consent to take part in the research. Initially, agreement to take part in the research was sought from the head teacher with the understanding that at any time during the planned interventions the school, or any individual child, had the right to withdraw from the research. Permission to conduct the research was granted in all the schools that were approached.

Phase 4 of the research could then take place and Oppenheim's (1992:83) statement of the basic ethical principle governing data collection that, *'no harm should come to the respondents as a result of their participation in the research',* was uppermost in my mind. Prior to administering each data collection task, children were fully aware that they did not have to take part and those that were reluctant to participate were not coerced to do so. Every response was regarded as acceptable and therefore the children were not placed in a knowingly stressful situation. These measures resulted in a high response rate, with relatively few non-responses although this factor did increase in Year 9.

Phase 6 involved one-to-one interviews and all participants were asked for their permission to conduct and tape record the interview. They were informed that their responses would be confidential and a private matter between the interviewer and themselves. Each interview was intended to last 30 minutes and was conducted in a quiet, but public, place within the child's school. The participants were encouraged not to guess at any answers that they were unsure about, but equally, participants were put at their ease by emphasizing that this was not a test.

3.6.3 The research report

The participants were informed that the research would be written up as a PhD thesis and any work would maintain the anonymity of the schools and participants. This has been achieved by attaching codes to each individual, rather than using real, or substitute names, so that anyone reading the research would not be able to identify schools or individuals.

It is of paramount importance to ensure that false claims or misrepresentations of the data do not occur. I have endeavored to analyze and present the data with honesty, in order to maintain the integrity of the research findings.

3.7 Location and participants

3.7.1. Location

The research presented here was undertaken in six maintained schools in two Local Education Authorities in the South of England. Two infant schools, two junior schools, one primary school and a large secondary school took part in the research. At the time of the fieldwork, all the schools involved in this study were broadly characterized by mixed socio-economic catchment areas, as judged by the reports for the schools from the Office for Standards in Education (Ofsted, 1999-2001).

3.7.2. The participants

The study involved 458 children, 176 in Year 2 (7-year-olds), 174 in Year 6 (11-year-olds) and 108 in Year 9 (14-year-olds). The children were all in separate year-group classes and were taught in accordance with the Programmes of Study of the National Curriculum, including science (DfEE/QCA 1999). The children who took part in this study were representative of the national range of attainment (Ofsted reports 1999-2001). Further details about the participants can be found in section 4.3.1 in Chapter 4. The relatively large sample of children involved during the initial stages of the study reflects the survey methodology employed. Approximately ten percent of children in each age group were followed up subsequent to the initial data collection. The children in this sample were interviewed individually to provide more detailed and in-depth information.

The fieldwork for the research took place during June and July 2003, towards the end of the academic year and at the end of each respective key stage. This point in time was chosen to ensure that all relevant programmes of The National Curriculum, for each age group of study, were completed.

The names of the schools and individual children involved in this study have been removed and replaced with a code to protect their identities and to ensure that the guarantee of anonymity and confidentiality was maintained. Ethical principles and codes of conduct for research involving human participants were adhered to throughout the research process and have been discussed previously in this chapter.

3.8 The curriculum and children's learning

Whilst it is recognized that children learn in many contexts other than formal schooling; nevertheless, one of the fundamental factors that affects what children learn and how they learn it, is the curriculum.

The development of the curriculum is subject to particular pressures and is often influenced by social and political expediency. The content of the curriculum, therefore, will alter over time. For example, concerns over 'the space race' ensured that theoretical and conceptual aspects of science predominated curricula in the 1960s (Fensham, 1994; Bentley, 1998), whilst moves to develop, 'a science for all', curriculum tended to focus on technological applications. More recently, the debate about scientific literacy has urged curriculum developers to consider social and ethical aspects of the science being learnt (Millar and Osborne, 1998; Reiss *et al.*, 1999). Roberts (1992) identified seven emphases within the science curriculum, each one conveying a different perspective about the nature of science. The predominance of the different emphases within the curriculum will, of course, affect what science is learnt and how it is learnt. This can lead to extreme outcomes, as Millar and Driver (1987) noted; for example, the differences between the highly content-driven secondary science curriculum compared to the process driven primary curriculum during the 1960's and 70's. However, curriculum developers have made attempts to prevent this isolation of the different aspects of the nature of science and more recent curricula have presented scientific content as concepts in context (Fensham, 1994).

3.8.1 The National Curriculum in England

The context for learning microbiology is highly relevant to teachers and children. The way in which subject content is presented and the approaches to teaching and learning that are adopted will have a profound effect on what children learn in this field. Microbiology merits exploration as much as any other area of science. Engaging in practical work wherever possible and gaining an understanding of what microbiologists have discovered in the past and what they currently do, will enable children to deepen their knowledge and understanding of micro-organisms. The National Curriculum advocates this approach to learning and teaching science. Since its inception, the National Curriculum in England (DfEE, 1989) has advocated the notion that the subject specific content of science should not be divorced from the processes of science but be taught and learnt alongside them. The current version of the National Curriculum makes this intention very clear, by stating at the beginning of the programmes of study, for each Key Stage, that, *'Teaching should ensure that 'scientific enquiry' is taught through contexts taken from the sections on 'life processes and living things',' materials and their properties' and 'physical processes'.* (DfES/QCA, 1999:78). This laudable ideal may not have worked, so well in practice, because of continued over-emphasis on content (Reiss *et al.*, 1999) and because in practice a narrow view about scientific investigation has been taken (Reiss *et al.*, 2002). This has certainly been the case in school microbiology, where there has been a significant reduction in practical work and that which was undertaken has tended to be more illustrative than investigative (Lock, 1996). Whilst it would not be suggested that children can only learn from a process driven curriculum and that secondary sources have to be employed, for example, in studying pathogenic micro-organisms, children's learning experiences are inevitably reduced without first-hand experience.

At the time of the research, all the children represented in this study had been taught the current programmes of study for science (DfEE/QCA, 1999). It is noteworthy that specific reference to micro-organisms appears only in the programmes of study for Key Stage 2 (7-11 years), and Key Stage 3 (11-14 years); no reference is made at Key Stage 1 (5-7 years). At Key Stage 2, children should be taught, *'that micro-organisms are living organisms that are often too small to be seen, and that they may be beneficial (for example, in the* *break down of waste, in making bread) or harmful (for example, in causing diseases, in causing food to go mouldy)* (DfEE/QCA, 1999:24). There are two references at Key Stage 3. The first focuses on human health: '*how the growth and reproduction of bacteria and the replication of viruses can affect health, and how the body's natural defences may be enhanced by immunisation and medicines'* (DfEE/QCA, 1999: 31). The second does not make micro-organisms a main focus of study, but are tangential to what the children should be learning, in that they are cited as a possible example for the study of populations. The work that children do in this area of science post Key Stage 2 seems to preclude a more holistic approach to the study of micro-organisms, by focussing on health and disease. The main thrust of learning about micro-organisms prior to Key Stage 4 is, therefore, undertaken at Key Stage 2. However, many of the children in this study would be expected to study the double-award science curriculum at Key Stage 4. Until the changes to the science curriculum for Key Stage 4 which were implemented from September 2006 (DfES/QCA, 2003) the double-award science curriculum expected children to be taught about, '*the basic principles of cloning, selective breeding and genetic engineering'* and '*the role of microbes and other organisms in the decomposition of organic materials and in the cycling of carbon and nitrogen'* (DfES/QCA, 2003:50). The statutory curriculum provision, for the study of microbiology, prior to Key Stage 4 does not seem to be an adequate foundation for future learning, given the expectations at Key Stage 4, taking into account the evidence that learning is not necessarily achieved after one period of instruction and that children's alternative ideas are resistant to change even after several episodes of teaching (Driver *et al.*, 1994).

3.8.2 Non-statutory schemes of work

In addition to statutory requirements, the Key Stage 3 National Strategy for Science (DfES, 2002) has been influential in developing the curriculum for pupils aged 11-14 years and draws on the DfES/QCA schemes of work (DfES/QCA, 1998). Whilst the move to include more microbiology, especially during Year 8, is welcomed, the Year 9 children in this study had not benefitted from this curriculum change. Non-statutory schemes of work to assist teachers in planning and delivering microbiology at Key Stage 2 and 3 are available (DfES/QCA, 1998). However, the units are very short. At Key Stage 2, pupils are expected to spend only 6 hours on the topic and, at Key Stage 3 the unit is expected to last 8 hours. It is interesting to note that whilst the National Curriculum at Key Stage 2 provides a statement that places the idea of beneficial micro-organisms and their activities before their non-beneficial activities, the DfES/QCA scheme of work does not begin to consider the more positive aspects of micro-organisms until the fourth section of a total of six. At Key Stage 3 the unit focuses on micro-organisms as agents of disease, yet the document indicates that the unit will provide a foundation for work in Key Stage 4 about the body's defences against infection and the uses of micro-organisms in biotechnology. This claim would seem to be difficult to achieve given the content of the unit of work.

3.8.3 Curriculum issues

The study of micro-organisms is given cursory coverage, at best, during the earlier stages of compulsory schooling and tends to focus on the more negative aspects of microbial activity. The essential role of micro-organisms in maintaining the balance within ecosystems, cycling of nutrients, traditional technologies and current biotechnologies are either only briefly covered, or left until Key Stage 4. Without a good foundation, prior to encountering some of these concepts, learning will be more difficult. This study aims to discover what children between the ages of 7 and 14 years know and understand about micro-organisms within the context of the National Curriculum and the study's findings may help to illustrate the adequacy, or otherwise, of current curriculum provision for microbiology.

A further issue is that many pupils are denied the opportunity to learn about very important aspects of microbiology if they do not follow double-award science at Key Stage 4, despite the stated expectation they will become scientifically literate. It would be very difficult for children to engage in debate, about specific issues, in an informed manner if they are not equipped with a knowledge and understanding of the basic science to refer to in the development of their arguments.

3.9 Summary

The research presented here aims to explore the ideas children have about micro-organisms and how the ideas they hold change with age and maturity. It attempts to do this by eliciting children's knowledge and understanding at ages 7, 11 and 14 years, using multiple methods within an overarching survey methodology. The research is framed within a constructivist view of learning science, which acknowledges that children construct their own knowledge, often in social contexts, in an active and dynamic manner and that the ideas they already have influence this process. An interpretive approach is adopted in relation to the research design and methodology which aligns with a constructivist view of learning and enables theory to emerge from the data.

Mental models to categorise the ideas children have about micro-organisms in order to be able to develop typologies that describe any changes and developments in knowledge and understanding between the ages of 7, 11 and 14 years.

The fieldwork for this research took place in six schools in the South of England and involved 458 children. All of the children in the study had completed the relevant programmes of study for science and the Year 6 children had undertaken the QCA short unit of work on micro-organisms (DfES/QCA, 1998). The current curriculum in England, with regard to microbiology, is explored and some limitations are identified that may restrict the ideas children have about micro-organisms.

Chapter 4

Research methods

4.1 Introduction

How research is conducted is important to the success of any project. Not only do the methods employed have to be appropriate for the nature of the data being collected, but also they need to be suitable for the participants in the study (Robson, 1993).

This chapter focuses on the methods employed to elicit children's knowledge and understanding of micro-organisms, within the context of a cross-age survey described in Chapter 3. A pilot study was conducted to inform the main data collection process and is discussed in the next section of this chapter.

4.2 Pilot study

The pilot study was designed to trial the research instruments, in order to provide an indication of the most fruitful and meaningful approaches, by which to elicit children's ideas about micro-organisms in three different age groups. Each respondent was given the same tasks and provided with the same instructions in order to ensure reliability of any subsequent analysis of the data. The language used during data collection was encouraging, in order to elicit the most accurate response. Analysis of the results from the pilot study identified the most useful activities, types of questions and the order in which they are presented, to avoid ambiguity and to ensure the most appropriate wording and clarity of meaning. This is an important aspect of any pilot research project and in this instance is further complicated by the wide age-range of the participants. It was important to neither patronize the older children, nor dumbfound the younger ones. Understandable, non-jargonistic and value free questions are the goal to aim at, whilst leading questions, or statements, are to be avoided.

It was thought that the size of the cohort would provide sufficient data to develop the most appropriate and worthwhile approaches for the main study.

4.2.1 The pilot study participants

The cohort was a random sample of children in Years 2, 6 and 9, who had been taught the relevant Programmes of Study for Science in The National Curriculum. Thirty children in total: ten aged 7, 11 and 14 years respectively, which represents the end of Key Stages 1, 2 and 3, were interviewed individually. The children attended LEA maintained schools that have catchment areas broadly representative of the whole school population in England and the primary is a feeder school for the secondary. The children for each age group were selected by teachers to represent the range of attainment in schools. The end of each key stage was chosen to furnish the spectrum of age and development required by the research, and as a critical point in the school career of each child.

4.2.2 Methods and methodology

The aim of the pilot study suggests that a survey instrument in the form of a questionnaire is an appropriate method to employ (Cohen *et al.*, 2007). However, the sample size (n=30) of this pilot study is, clearly, far too small to be suitable for a survey and the age-range of participants makes the production of an appropriate questionnaire extremely difficult. Hardey (1994) indicates that the interview is akin to a purposeful conversation, in which participants elaborate upon ideas and questions that the researcher provides within the framework of an interview. The information required to inform the development of appropriate, main study research tools indicates that a one-to-one, semi-structured interview, largely in the control of the interviewer is a suitable approach to take for the pilot study. The interview made use of multiple methods, by giving children a range of tasks, which required distinct responses during the course of the interview, in order to elicit a variety of data on the same topic. Consequently, the interview included open and closed questions, projective methods including concept maps and annotated drawings, probes and other visual stimuli for a simple sorting task. The interview schedule can be found in Appendix 1.

4.2.3 Knowledge and understanding of micro-organisms

It is important to have a recognised, authoritative consensus about the particular phenomenon, or field of study in research like this, where the aim is to discover cognitive conceptions: in this case, children's ideas about micro-organisms. A sound knowledge base will enable productive interpretation of data and allow reliable judgements to be made about the participants' level of knowledge and understanding. The summary, outlined in Chapter 2, section 2.10, which was employed to develop the interview schedule, offers a scientifically accepted view of micro-organisms.

4.2.4 Knowledge and understanding probed during the interviews

In order to determine the parameters for the questions that might be appropriate to ask children during the interview, the knowledge and understanding probed during the interviews was not entirely based upon the accepted knowledge of micro-organisms discussed in the previous section. The questions were adapted to focus on what children are expected to know and understand about micro-organisms from their school science, as defined by the National Curriculum (DfEE, 1999). The research literature abounds with evidence that knowledge and understanding is not only obtained from school curricula (Piaget, 1929; Gilbert *et al.,* 1982; Carey, 1985; Osborne and Freyberg, 1985; Driver *et al.,* 1985b; Tunnicliffe and Reiss, 2000). These studies indicate that children come to their science lessons with a predetermined set of ideas about how the world works, based upon common sense observations of phenomena and they use these to build, or change, their conceptual understanding when faced with new experiences. The *tabula rasa* view of how children learn and therefore how they can be taught is now consigned to history. A broader interpretation of how children acquire their knowledge and understanding of micro-organisms was adopted to include information that children have acquired through their personal experiences and by exposure to other sources of information, such as the media, home, family and friends. The stance adopted allowed for a deeper exploration of ideas than would have been possible if the interview had remained confined to the prescribed National Curriculum content. Indeed, if the interview had been confined to the *expected* knowledge and understanding based upon the National Curriculum for each year group, comparison of responses between the age groups would have been difficult. The interviews probed the themes discussed in the review of the literature in Chapter 2 and responses were judged against the scientifically accepted knowledge and understanding of micro-organisms discussed in Chapter 2. Table 4.1 indicates the relationship between the literature review themes and the key conceptual areas explored during the interviews.

Table 4.1
Areas explored during the interviews in relation to the literature review themes

Interview	Literature review
o Language and terminology associated with micro-organisms; o Variation (bacteria, fungi and viruses only)	Classification
o Micro-organisms as living organisms	Living and non-living
o Structure of micro-organisms	Morphology
o Size of micro-organisms	Size and scale
o Importance to humans (agents of disease, agents of controlling disease o Food spoilage	Disease, heath and infection control Decay
o Ubiquity of micro-organisms o Importance to ecological systems (cycling of nutrients, decomposition and decay, transfer of energy through ecosystems i.e. photosynthetic and other autotrophic organisms, bioremediation)	Ecology and ecosystems
o Importance to humans (agents of controlling disease, food production (traditional and new technologies)	Technological applications

4.2.5 The interview process and schedule

Procedures for the interviews were maintained in accordance with the British Educational Research Association's ethical guidelines for interviewing (BERA 1992) and guidelines for interviews offered by other sources (e.g. Osborne and Freyberg, 1985; Robson, 1993; Dawson, 2002). All participants were asked for their permission to conduct and to tape record the interview. They were informed that their responses would be confidential. Each interview was intended to last for 30 minutes, but in fact they lasted approximately an hour, with some taking longer. The participants were encouraged not to guess at any answers that they were unsure about and were put at their ease by emphasising that this was not a test. Tape-recording the interviews was considered to be the most effective way of capturing data (Powney and Watts, 1987; Dawson, 2002) and field notes, and all drawings and written work were retained for subsequent analysis.

A series of open-ended and closed questions, together with drawings and physical props were used to obtain information about microbial structure, habitat, and activities. After completing a drawing of a micro-organism, participants were asked to undertake a brainstorming activity, in which they could write down everything they knew about micro-organisms. Both activities were considered to be techniques to gather children's knowledge and understanding spontaneously, in a non-threatening way and yet yield information about what was internalised within their cognitive structures (White and Gunstone, 1992). A picture-sorting activity was used to round off the interview, in what was considered to be an entertaining way. The different techniques employed throughout the interview acted as a means of triangulation and increased the validity of the data obtained. Finally, the participants were asked if they wanted to include any other thoughts, or ideas. They were thanked for their help and time.

4.2.6 Findings and discussion

The interviews were analysed by transcribing taped recordings and categorising responses. As a result of the analysis, responses were placed into broad, 'themes'. Particular aspects within the themes became apparent and these were categorised. Quantitative tallying within each category was completed. In this way, both a qualitative and quantitative picture of the responses within each age group was obtained. Comparison between the age groups was then possible.

The key themes that emerged were consistent with the ideas probed in the interview:

- general knowledge and understanding of micro-organisms ,which includes ideas about structure, size, location, living or non-living and source of knowledge;
- micro-organisms as agents of disease, virulence, mode of infection, immune response;
- micro-organisms as the cause of decay and decomposition, including products of decay, cycling of nutrients and the effects of decay;
- applications of microbial activity and the use of micro-organisms to produce food and medicines.

Overall, the children's knowledge and understanding of micro-organisms, increased with age and the greatest increase in knowledge and understanding occurred between Year 2 and Year 6. However, reasoning, even amongst 14-year-olds, is still at times contradictory and alternative ideas were present in all the children's thinking.

The results indicated that children in all the age groups studied have a partial knowledge of micro-organisms, although alternative and contradictory ideas were evident in all children's responses. Anthropocentric ideas are represented in all age groups. Micro-organisms are seen as unhelpful and their principal function seems to be as the causal agents of disease. The beneficial activities of micro-organisms, naturally occurring, or controlled by humans, are not well understood. The knowledge children have tends to be atomistic, with few connections made between different concepts; for example, how micro-organisms affect other living things, or interact within ecosystems. This may be due to how different topics, such as decay and cycling of matter are taught. The observed increase in knowledge and understanding during the primary years is likely to be, in part, a result of school teaching, although revising for National Tests could have been a factor in the results obtained from the Year 6 children.

4.2.7 Evaluation

On completion of the pilot study, the methods employed and the findings resulting from the data analysis were considered. Several issues became evident and were used to inform the main study; these included the methodology and data collection tools and the areas of knowledge and understanding probed. The alterations are summarised in Table 4.2 and discussed below.

Table 4.2
Summary of alterations to main study as a result of pilot study

Pilot study	Main study
Interview only	Drawing, brainstorm, concept map to whole cohort Interview up to 10% of cohort
Picture sorting exercise	Concept maps
20 pictures / photographs	11 photographs
Photographs include illustrations of concepts beyond expected knowledge and understanding by the end of key stage 3, e.g. bioremediation	Photographs focussed on key themes of expected knowledge and understanding by the end of key stage 3 only
Interview included emphasis on terminology and classification	Reduced emphasis on terminology and classification, but refer to children's drawings
Some question sequences not useful	Order of some questions altered

Whilst the different methods employed within the interviews yielded valuable data, in the pilot study, they made the length of each interview too long and beyond the suggested time, of less than an hour, for a productive interview, especially with children (Robson, 1993). For these reasons the drawing activity and brainstorm were administered separately, to a larger sample than those who would be interviewed in the main study. The picture-sorting exercise was also time consuming and was not as successful as had been anticipated. In addition, some photographs, for example, the oil slick which requires knowledge and understanding of microbial bioremediation, proved to be beyond the sphere of any child's knowledge and, as a consequence, certain photographs included in the pilot study, were eliminated from the main study. The sorting activity was employed to elicit children's ideas about microbial activity and to begin to explore any connections that they might make between these activities. Making links between ideas illustrates how different aspects of knowledge are related to each other in the mind of a participant. These links provide an indication of the level of sophistication of subject knowledge and understanding (White and Gunstone, 1992). Therefore, a form of concept association technique, using photographs, was considered a worthwhile technique to employ in the main study. The whole sample would be asked to produce a concept map using labelled photographs.

Continuing to include a range of methods in the data collection for the main study maintained elements of triangulation and, by reducing the number of activities within the interviews, the time for each interview would be condensed to an acceptable limit.

Findings suggest that most of the youngest children did not know the term 'micro-organism' and I had to refer to 'germs' during these interviews. Therefore, despite the misgivings about the unscientific nature of the term it was decided to continue to use this in the main study. The terms used by children to refer to micro-organisms appear to be interchangeable and it was decided that more fruitful data could be obtained in the main study if less emphasis was placed upon terminology and classification, whilst more was placed upon appearance and microbial activity. In accordance with this change, the interview schedule was amended to include reference to the drawing each interviewee had produced. The wording and order of questions for some aspects of the interviews was also altered.

4.3 Main study

The main study took place during the summer term of 2003 in one primary school, two junior schools, two infant schools and one large comprehensive secondary school. This time was chosen to coincide as closely as possible with the end of the children's formal learning within a particular Key Stage of the National Curriculum and after they had been assessed through national tests (Key Stages 2 and 3) and teacher assessment (Key Stage 1).

Ethical protocols and procedures were adhered to and have been fully discussed in Chapter 3. Permission was sought in the first instance from the head teacher of each school. The nature of the research was described and each research method was explained. The interview schedule and photographs for the concept mapping exercise were discussed. The anonymity of each participant was guaranteed and I agreed that if any child was reluctant to participate, they would not be put under any duress to take part. One head teacher wished to consult with the parents of the children. After agreement had been reached, permission to conduct the research was granted in all the schools I approached. The teachers and children were also consulted and their agreement to take part was reached before the main data collection began.

4.3.1 Participants

The participants in this study were children aged between 7 and 14 years. A total of 458 children, 176 aged 6 years, 174 aged 11 years and 108 aged 14 years were involved in the research. The children were all at the end of a Key Stage within their formal schooling. All children attend Local Education Authority (LEA) maintained schools and they had been taught the relevant programmes of study in the national curriculum for science, within the appropriate key stage. The schools are all in the South of England and have catchment areas that provided the sample of children to be broadly representative of the whole population. They included two infant schools, two junior schools, one primary school and one secondary school. National test data were obtained for the majority of the sample and a summary of the results of the Standard Attainment Tests for the children in this study compared to the total school population for each year group is presented in Table 4.3. The figures show that the results from the sample can be considered as broadly in line with those of the whole population indicating that the sample is representative of the total populations for the age groups studied. Some discrepancy between the total sample and the national sample exists because of absences on the day of the test and, at Key Stage 2, one head teacher would not release the results for her school. This may be the reason for the apparently skewed results in Key Stage 2 compared to the total population

Table 4.3
National Test scores for children in this study and the national population for 2003

Yr. group / N.C .level	2 % Study sample N =175	2 % National population	6 % Study sample N =138	6 % National population	9 %Study sample N =103	9 % National population
pre 1	1.1	2	0	0	0	0
1	4.0	9	0	0	0	0
2	71.4	64	0	0	1.0	0
3	23.4	26	1.4	10	6.8	8
4	0	0	30.0	46	21.4	18
5	0	0	69.6	41	17.5	28
6	0	0	0	0	26.2	29
7	0	0	0	0	26.2	11

Note: numbers differ from whole sample due to absences and unavailability of results for Year 6 in one school of this study.

The children worked in their normal class groups during the two main elicitation phases and the researcher, class teacher and teaching assistants were present. One-to-one interviews were held after an initial analysis of the drawings and concept maps. Interviews were held in the children's school, but in a quiet area. Approximately ten percent children from each age group were selected to be interviewed and these were chosen to provide a representative sample of the cohort, whilst at the same time representing the variety of ideas presented in the drawings and concept maps. This was achieved using intensity sampling and deviant, or extreme, sampling (Mertens, 1998); a full discussion can be found in section 4.4.1.below.

4.4 Validity and reliability of the research methods

Research must endeavour to provide information that is trustworthy and believable (Mertens, 1998). The researcher needs to consider the quality of the data collection strategy by establishing indicators that provide evidence of the quality of the data with respect to validity, reliability and objectivity.

Reliability is concerned with the repeatability of data collection methods and the consistency of the type of data that is collected (Denscombe, 1998; Mertens, 1998). With this in mind, another person rated the scores given to the photograph association concept map propositions; thus providing an inter-rater reliability exercise using Cohen's Kappa (Cohen, 1960). Details are in section 4.7.2 of this chapter.

Conventionally, validity is concerned with the extent to which the data collection method measures what it was intended to measure (Oppenheim, 1992; White and Gunstone, 1992). Denscombe (1998) adds that the notion of validity hinges around whether or not the data reflect the truth, reflect reality and cover crucial matters, in other words the extent to which the data and methods for obtaining the data are deemed accurate, honest and on target. However, in reality, Mertens (1998) has a more pragmatic approach when she points out that the validity of an instrument is assessed in relation to the extent to which evidence can be generated that supports the claim that the instrument measures attributes targeted in the proposed research. With this in mind, several research tools were employed within the research presented here and all claim that they will provide information about children's ideas about micro-organisms.

4.4.1 Sampling

A further consideration, in terms of validity, concerns the sample of respondents used in the research to ensure that they are representative of the population, in order that generalisations can be made about the data collected.
Small-scale research, such as the study presented here, requires great care in the selection of the sample. Denscombe (1998) stresses that several key issues need to be taken into account when undertaking small-scale research with relatively small sample sizes:

- extra attention needs to be paid to the issue of how representative the sample is and caution is needed about the extent to which generalizations can be made on the basis of any research findings;

- the smaller the sample, the simpler the analysis should be; in the sense that the data should be subjected to as few sub-divisions as possible;

- inferences drawn from the statistical analyses on sample sizes of around 30 should be considered with care and sensitivity.

However, this does not mean that research with small sample sizes does not produce valid findings, simply that caution must be observed when ascribing particular generalisations or claims about the findings. This type of research is probably well suited to quantitative and qualitative forms of data analysis, rather than one or the other. This will be an advantage in analysing the findings presented here.

a. The respondents

Mertens (1998) suggests that the researcher has several options in obtaining information from a survey. The researcher can choose to ask the persons directly experiencing the event, in this case the children being taught, about micro-organisms, or persons who know about the experience, who would be the teachers or interrogate the records of the event; for example, the curriculum plans and assessment records. In this study, a decision to ask the children's teachers about what the children had studied in relation to micro-organisms, examining the curriculum plans and the children's assessment records could have been made. However, this approach would not have provided the richness and the detail of data required to answer the research questions in a satisfactory manner, although it is acknowledged that this would have provided some background information for the study. Children's ideas, rather than what has been prescribed for them to learn, or how well they have learnt it, are the primary focus of this study and it is therefore appropriate that children, rather than a proxy source of information, are the respondents from whom a sample group is drawn. Other sources of information, in the form of end Key Stage national test scores in science, were also sought to provide further information about the sample.

b. The sample size

According to Mertens (1998), the type of research that is being undertaken will determine the sample size, and a rough, 'rule of thumb'; can be applied to determine sample size. Borg and Gall (1989) have recommended appropriate sample sizes for different types of research. They suggest that survey research, of which this study is an example, should ensure 100 observations for each major subgroup, and 25-50 for minor subgroups. The research described here has employed this guidance having at least 100 children in each age-group sample, which is subdivided by gender into approximately equal numbers of boys and girls. The final sample interviewed, in the third phase of the fieldwork, represents between seven and ten percent of the total population in each age group (7% for Year 2 and Year 6 and 10% for Year 9).

c. The sample population

Having identified the general nature of the respondents, a sample population must be selected because time constraints, finance and other practicalities, such as accessibility and size of the population, do not permit a whole population to be studied. As Mertens (1998) says, the conceptual definition of the population has to be translated into operational terms. The sample represents a whole population and the characteristics of that population are inferred from the responses provided by the sample. However, the strategy used to select the sample will influence the quality of the data obtained and the inferences that can be deduced from it (Mertens, 1998). The nature of the research may influence the type of sampling strategy employed. Normative or positivist researchers tend to employ a form of probability sampling. Here a sample is selected in such a way that every member of the population has the possibility of being included in the sample, resulting in a reasonable cross-section of the population being represented. In contrast, research falling into the interpretive paradigm tends to use theoretical, or purposive sampling, which begins with the identification of groups, individuals, or settings where (or for whom) the focus of the research is most likely to occur (Denzin and Lincoln, 2000). Some (e.g. Henry 1990) consider that randomised probability samples are the, 'ideal', and the most effective because of the possibility of rigorous analysis of sample bias, which in turn, confers greater validity to the data and therefore the generalisability of any findings. However, despite the apparent advantages of this approach, it is rarely used in educational research (Mertens, 1998). The population of interest in this small scale study consists of all the children in Local Education Authority (LEA) maintained schools throughout England; it is by definition widespread and very large, and with sample sizes of about 100, probability sampling is quite simply impossible.

Mertens (1998) suggests that most research in education tends to choose the sample using non-random methods. However, she warns that non-random does not equate to whatever happens to be available and that all researchers must make a conscious choice with regard to the sample, rather than accepting whatever is merely convenient. With these issues in mind, the research described here initially employed a cluster and stage sampling technique, which offers a compromise between a totally random and totally non-random sample population (Denscombe, 1998; Mertens, 1998). A smaller sample of 'cases' were subsequently selected through a combination of intensity and extreme, or deviant, case, sampling methods.

Cluster sampling is possible when 'naturally 'occurring groups of individuals, in this instance, children in L.E.A. maintained schools, are the particular focus of interest to the researcher. It is considered to be possible to obtain a, 'good enough', sample by randomly choosing a 'naturally' occurring group and studying all (or a random sample of) the individuals in the cluster. Multi-stage sampling involves a combination of sampling strategies and involves taking samples from samples. Cluster and multi-stage sampling may involve several stages and different levels and Henry (1990) points out that the more strata in the sampling process, the more representative of the whole population the sample is likely to be. Two L.E.A.s in the South of England were identified as 'naturally' occurring clusters of children. Stage sampling selected two infant, two junior, one primary and one secondary school as smaller, but still, 'naturally', occurring clusters of children. All the children in Year 2 and Year 6 were selected from the primary school whilst stage sampling occurred in selecting two of the three classes in Year 2 in the infant schools, two of the three classes in Year 6 in the junior schools and 4 out of10 classes in Year 9 in the secondary school. All the children, in each class selected, undertook the tasks of Phases 1 and 2 of the fieldwork.

Intensity sampling was employed to select children from the original sample in each age group, to be interviewed. The use of intensity sampling enables the researcher to identify those individuals in whom the phenomenon of interest is strongly represented; in this case knowledge and understanding of micro-organisms or the lack of it. The researcher looks for phenomenon rich cases which are not necessarily extreme; this requires knowledge of the individuals. In this study, that information was obtained by scrutinising data from Phase 1 of the fieldwork. A representative sample was achieved by categorising the drawings and brainstorms into two main groups; those with mainly accurate ideas and those with mainly inaccurate, or no ideas. These large groups were subdivided to correspond to the main ideas found in the pilot study; these were:

- appearance including structure and size;
- living;
- location or habitat;
- microbes as agents of disease;
- other microbial activity including microbial applications.

Some children's drawings and brainstorms could be placed into more than one group; in these instances, the majority of ideas represented was used to categorise them.

However, this method provided an excess of 'cases'. Extreme, or deviant, sampling was employed to reduce the cases to 12 for each age group. The idea behind this sampling method is that the researcher identifies unusual or atypical responses, with the view that a study of extreme cases may yield information about the more typical situation. Mertens (1998) indicates that the normal situation will be illuminated by studying the extraordinary. The drawings and brainstorms that contained the most accurate, or unusual, answers were selected from each group. This was considered to be a way of representing the full range of views from the cohort. A random sample from this smaller sample was subsequently selected for interview.

Whilst every effort has been made to select a sample as representative of the whole population as possible, it is recognised that the schools and classes of children involved in this study have not been selected truly at random. Factors associated with research in educational settings, such as accessibility, willingness to participate, internal organization and management structures, permission from parents and other ethical issues have constrained the sample selection. That said, the sample chosen might be considered to be representative of a sample frame which included the entire population of primary and Key Stage 3 children in all LEA maintained schools in England following the National Curriculum, for the academic year 2002 / 2003 at least.

4.5 Research methods and instruments

It was intended that the variety of methods employed and different techniques used within the field work would enable children's ideas to be probed in depth and from different perspectives, allowing knowledge and understanding to be elicited. This approach provides, not only an overview of the level of knowledge and understanding, but also the qualitative and quantitative changes that may occur at each age group. Furthermore, it was anticipated that this information would allow models and typologies of children's ideas, with respect to micro-organisms at the three different ages to be developed. These models and typologies may also help to offer further insight into how children's ideas and learning about micro-organisms develop with age.

A survey strategy administered through multiple method instruments was considered to be the most appropriate way to elicit children's ideas. The instrumentation was trialled and subsequently amended as a result of the pilot study, which was discussed previously in section 4.2.7. I endeavoured to ensure that the instruments used during the main phases of data collection had instructions that were understandable to all participants, tasks that were achievable by all participants, props that were familiar to the participants and questions that were in a suitable order and worded to avoid ambiguity. Consequently, the methods and instruments employed were considered adequate to provide sufficient data needed to answer the research questions.

The research instruments and methods were employed to obtain children's ideas about micro-organisms on different occasions, using four distinct methods. The value of using multiple methods is discussed in the next section.

4.5.1 Multiple methods

Very often surveys and other educational research are characterised by a single method approach (Denscombe, 1998). This can be considered as a vulnerable form of data collection, because it offers the researcher a sole perspective on the problem and therefore may provide a skewed version of reality, but certainly can lead to the likelihood of a paucity of data. However, for small-scale research, such as that described here, there is no 'perfect' method and the possibility, therefore, exists of using a variety of methods to collect data about the same thing. Denscombe (1998) elaborates that an important outcome of methodological triangulation is the opportunity to compare and contrast findings, produced by the different methods, because it allows the findings to be corroborated to enhance the validity of the data. This does not mean to say that the researcher has got it right, but by using multiple methods they can credit the meaning of the data with some validity because they are not tied up with a particular method. However, the researcher must be careful not to assume that, by using multiple methods an absolute, or single truth, will emerge and must not presume that multiple-method research can prove that the data, or analyses, are absolutely correct. The researcher must always be vigilant in considering issues that can affect the data. Having said that, multiple methods are more likely to provide a depth and richness of data, to enable different perspectives to emerge and improve the quality of findings and increase their validity (Denzin and Lincoln, 2000). It was for these reasons that multiple methods were chosen to elicit children's ideas about micro-organisms.

4.5.2 Methods

It was essential to use methods that were suitable for the wide age range that this study involves. Questionnaires, often used in survey research, can provide a great deal of information in a standardised form which is subsequently easy to analyse, but they do not provide the detail required to discover the extent or complexities of children's ideas explored here. Good questionnaires are notoriously difficult to design (Oppenheim, 1992). A questionnaire has to be readable and understandable by the respondents; the difficulties in designing a questionnaire, so that all of the children between 7 and 14-years-old employed within this study could complete it successfully, are tantamount to managing the impossible. A conventional questionnaire, administered for participants to read and complete alone, was therefore rejected, as an appropriate means of data collection, although for different but related reasons to its rejection in the pilot study. However, Phases 1 and 2 of the field work can be considered as consistent with a questionnaire-style method within the framework of a survey strategy, given that the children were, within reason, all asked to perform the same tasks and given the same instructions by the same researcher at the same time. Whilst this forms the overarching research design, the view taken here is that the different tasks actually employ distinct methods of data collection. Some of the tasks that originally formed part of the interview procedure during the pilot study were administered separately during the main study for the reasons given earlier, during discussion of the pilot study. The multiple methods used within the research are all considered suitable for a wide age range and are described below. The methods were designed to elicit all the key conceptual areas with the exception of the concept maps which focussed disease, health and infection control, ecology and ecosystems and technological applications.

a. Drawings

Drawings have not been used extensively to elicit children's ideas in research, although they were used effectively in the Science Process and Concept Exploration Project (e.g. Russell and Watt, 1990; Osborne *et al.*, 1992) to discover children's ideas about a variety of scientific phenomena. Hayes *et al.* (1994) suggest that the potential of drawing as a research tool has not been thoroughly exploited, despite its advantages in obtaining information that offers a complex and rich source of data. Reiss *et al.* (2002) concur with this view and add that drawings provide a useful method of gathering a rich mass of data with relative ease, where language is a possible barrier to understanding. In the study presented here, different languages are not an issue; nevertheless the wide age range of the participants makes the simplicity of the research method a useful one. Furthermore, inviting children to draw, a micro-organism in this case, allows them to focus on the topic in a non-threatening way. The opportunity to write what the picture is about can then occur more naturally and the child is more likely to write more and consider their ideas more deeply, because they are less nervous, more relaxed and not afraid of getting it 'wrong'.

Interestingly, drawings have been used extensively in the field of health education (Williams *et al.*, 1989; Box and Landman, 1994; McWhirter and Weston, 1994; Collins, 1995; Wetton, 1995), where the aim has been not only to discover what children know about a particular issue, but also how they feel about it and to discover their attitudes towards it. Drawings are considered to be a projective technique (Oppenheim, 1992) and thought to be a good way of discovering an individual's inner thoughts, attitudes and ideas. They allow the researcher to obtain information from the respondents that might otherwise be missed by more direct methods.

Reiss *et al.* (2002) also suggest that drawings can represent a child's expressed model of a particular phenomenon which is placed in the public domain. Whilst these models relate to, but do not equate with, their mental models (the private and personal cognitive representations), they can provide a useful guide to children's ideas and supplement other research methods. The draw and write technique (Williams *et al.*, 1989), developed and used worldwide, has been adopted as the first method with the research here. The children were asked to draw a picture of a micro-organism and then write down anything about their drawing that they wanted to.

The 7-year olds were asked to draw a germ and, as discussed earlier, it was found during the pilot study that they did not recognise the term micro-organism or microbe. Despite the negative connotations and, to some extent uni-dimensional concepts associated with the term 'germ', it was felt imperative to employ a term that all the children in this age group knew, rather than something that would have resulted in a very low response rate.

b. Brainstorming

Controversy exists over the term 'brainstorm' due to the offence it might cause people with certain brain conditions (McDonald, 2005). I could have used the suggested alternative term 'thought shower' but 'brainstorm' is commonly understood by school children and rather than use a less familiar term I decided to retain 'brainstorm'. Brainstorms are normally associated with group work to generate a large number of ideas for a solution to a problem (Osborn, 1953). However, because the technique allows free rein to think about a topic or concept and generate ideas successfully in a variety of contexts and for a variety of purposes (e.g. MacPhail, 2001; Taxen *et al.*, 2001; Troia and Graham, 2002), brainstorming was considered as a useful method in this study. It allowed children the opportunity to undertake a free thinking exercise to write down anything they knew about micro-organisms. The children who could not write were offered a scribe, although the scribes were instructed not to provide the children with any additional ideas. Brainstorms are not a usual method of collecting data from children for research purposes. However, it was deemed in this study a highly appropriate method, as it allowed a great deal of information from a relatively large number of children to be collected in a short time. Brainstorming is also a technique with which all the children in the sample are familiar and would not require extensive instructions, or training, to complete the task.

Furthermore, allowing the children to complete their annotated drawings before they complete the brainstorms would allow them to feel more relaxed and less threatened. In this way, more useful and valuable information would be obtained because the participants are relaxed and 'in tune' with the subject matter.

c. Photograph association concept maps

Concept maps are a visual representation of the relationship between different concepts. Where a relationship between concepts is thought to exist, connecting lines, or arrows are drawn between them and the relationship is articulated in linking phrases. Concept maps, therefore, allow individuals to indicate their understanding of the relationships between ideas, things or people (White and Gunstone, 1992, van Zele *et al.*, 2004). Novak and Gowin (1984) elaborate this point by stating that concept maps allow the content, structure and relations of children's ideas to be explored, simultaneously. The linking statements, known as propositions (Novak and Gowin, 1984), between concepts indicate the level and complexity of understanding and it is this aspect of concept mapping that is employed in this research project. Concept maps and concept mapping, as pedagogical tools for planning instruction, or assessment, have been the focus of a great deal of research (e.g. Barenholz and Tamir, 1992; Kinchin, 2000a; Van Zele *et al.*, 2004; Yin *et al.*, 2005). Although, as Van Zele *et al.* note, the use of concept mapping as an assessment tool is less frequent than as an instructional tool and this may be why concept mapping, employed as a data collection technique for discovering children's ideas, *per se*, is rare. However, concept maps provide the researcher with a relatively efficient mechanism for eliciting the relationships children may hold between concepts; in this instance the concepts about microbial activity.

The challenge within the context of this research was to design a tool that would be accessible to, and possible to complete by, each age group. Kinchin (2000a) considers that concept maps are a useful way of collecting information, and because they are flexible, they can be adapted for use by almost any group of learners. It was for these reasons that concept mapping was adopted as a useful method for this research project. However, conventional concept maps require reading skills that were likely to be beyond the younger children in this study. The picture sorting exercise had been a popular activity during the pilot study and despite its limitations, discussed in section 4. 2. 7, it had been a productive way of eliciting information. As the reading age of the children in the sample was so varied, it was decided to make use of a photograph association approach. Combining the use of photographs and concept mapping techniques offered me an opportunity to develop a new research tool. I considered that using photographs, that are associated with aspects of microbial activity, would allow children across the age range to produce a visual representation of their knowledge structures (van Zele, *et al.,* 2004). Concept mapping using a photograph association technique (CoMPAT) is something quite innovative.

Each child was given a sheet of named photographs and they were asked to select the photographs that they considered had any connection with micro-organisms. The children used the chosen photographs to produce their concept maps by cutting them out and sticking them onto a sheet of A3 paper on which that they had already placed the term 'micro-organism' or 'germ'. They were asked to draw lines between the photograph and the term and state the connection between the photograph and the term. They were also asked to make connections between the photographs and to add any additional ideas if they could. This novel approach was devised in order to be able to work productively with a large number of children across a broad age range.

The photographs (Appendix 4a) were chosen to illustrate a range of microbial activities and based upon key concepts which emerged from the pilot study and which children should have some knowledge of by the end of Key Stage 3 as a result of school teaching. The photographs also were those that children had most frequently selected during the pilot study exercise. They were:

- Disease, health and infection control (sick child, antibiotics, vaccination and bleach);
- application of micro-organisms in traditional food technology (bread, beer, yogurt) and medication (vaccination and antibiotics);
- decay and cycling of matter (mouldy bread, sour milk, compost heap, sewage works) and environmental applications (compost heap and sewage works);

The photographs provided more beneficial than non-beneficial examples of microbial activity, which is more representative of reality, rather than the negative perceptions about micro-organisms identified in the pilot study.

d. Interviews

As a result of the data collection procedures described above, information was obtained about children's ideas about micro-organisms from differing perspectives. The drawings were analysed and a sample of children from each age group was selected to be interviewed. Full details of the sampling methods used to select the interviewees are discussed in section 4.4.1 in this chapter. It was intended that the interviews would provide an opportunity to enrich the data set further.

According to Denscombe (1998), interviews are often seen as a desirable option by researchers because of their apparent simplicity, although the process of interviewing is much harder than it would appear. (Fontana and Frey, 2000). Powney and Watts (1987) and Denscombe (1998) warn that considering interviews as akin to conversation is fraught with danger and will result in a poor outcome. Like any other research tools, interviews require proper preparation and Denscombe (1998:110) indicates that an understanding on the part of the researcher of, '*the sensitivity to the complex nature of the interaction during the interview itself*', is essential to its success. Consequently, the interview schedule was carefully piloted to ensure that questions were asked in an appropriate manner, that questions and tasks were achievable and due care was taken to make the interviewees comfortable and relaxed. The interview procedure itself took into account the procedures and protocols of interviewing, which were discussed earlier in the chapter.

The rationale for using an interview is that the researcher wishes to collect in-depth and detailed information from relatively few people, rather than a superficial amount of data from a lot of people (Denscombe, 1998). Rather than competing with other research methods, they can be used in conjunction with them, especially when used as an, 'information gathering tool'. An interview procedure is highly suited to gathering information about children's ideas. Furthermore, the interview has been used in conjunction with other means of data collection, in order to add detail and depth to the data (Abdullah and Scaife, 1997), and, in this instance, it is used to triangulate information, using a different approach (Flick, 1998; Cohen *et al.*, 2007).

Interviews can range along a continuum from completely unstructured to highly structured (Robson, 1993; Fontana and Frey, 2000). According to Cohen *et al.* (2007) and Fontana and Frey (2000), unstructured interviews yield more in-depth and diverse information compared to structured interviews, but the resulting data is more difficult to analyze. In this case, the analysis was intended to provide qualitative and quantitative data about children's knowledge and understanding about micro-organisms. Unstructured interviews also require a highly skilled interviewer if data / information is to be of value to the research focus. Highly structured interviews, on the other hand, allow for more comparisons between respondents (Wells and Marwell, 1976; Fontana and Frey, 2000), but they need a very carefully structured schedule which has been piloted very thoroughly. The information is highly standardized and does not necessarily provide respondents with the opportunity to elaborate on their answers; however, the skill of the interviewer is not so important. A semi-structured interview, largely in the control of the interviewer, offers the level and depth of information required in this project, because it offers respondents the latitude of adding information that they think is important, without losing the structure of the interview schedule and ensures that all the respondents give answers to specific issues. Analysis and comparison of interviews is therefore easier than an unstructured interview, but richness in the quality of the data is possible without losing the specificity of the issues being researched. The balance between the value of in-depth data, comparative data and time, provided the rationale for the research to include interviews that were semi-structured, but largely in control of the researcher.

4.5.3 Summary of methods

The multiple methods employed during the fieldwork provided the opportunity to elicit children's knowledge and understanding of micro-organisms in a variety of ways. These approaches should enable a comprehensive picture to be built up of what children at the specific ages in this study know and understand about micro-organisms. It should be possible to develop a model of the ideas at each age group. In addition the use of the same methods for each age group will enable comparisons to be made between age groups and some understanding of how children's ideas about micro-organisms develop with age should emerge.

4.6 Data collection

The three main phases of the field work and data collection occurred during late June and mid July 2003 and followed the outline provided in Table 4.4. Phases 1 and 2 were completed on the same day for each class. The first two tasks were administered to seven separate classes of children in Year 2 and Year 6 and to six classes of children in Year 9. It was intended that a seventh class of Year 9 children would be involved in the study, but, due to unforeseen circumstances, this was not possible.

During Phases 1 and 2 the children were working in their normal classrooms. The teachers and other adults in the room, except me, were those that would usually be there at that time. This enabled the data collection to take place in as normal an environment as possible. All the children in the study were given the opportunity to ask the adults in the classroom for help in writing what they wanted to say, or to read the labels on the photographs, although no other help was to be given and the children were aware of this. This was particularly important, especially for the youngest children, in order to capture as much information as possible and for that information to be the children's own ideas.

Table 4.4
Phases of data collection for main study

Phase	Method	Participants	Timing
1	Drawings and brainstorm exercise	Whole classes from each age group	Morning (I hour)
2	Photograph association concept mapping exercise	Whole classes from each age group	Afternoon (1 hour)
3	One-to-one interviews	10 individuals from each of the three age groups	Two weeks after Phases 1and 2 (30-40 minutes)

a. Phase 1

The first phase of fieldwork consisted of working with whole class groups to elicit their ideas about micro-organisms and microbial activity. Two separate research methods were employed. They involved the children in open-ended tasks and were akin to projective techniques, where the intention is to discover deep-seated ideas and, in many cases, opinions, although that was not the intention here (Oppenheim, 1992). Pupils were given a blank sheet of paper and asked to draw a micro-organism and then annotate their drawing. When they had finished their drawing the children were invited to turn over their paper and write down anything else they knew about micro-organisms in a brainstorming exercise. This was designed to elicit additional information from the children, in as a spontaneous way as possible. Finally, the children were asked to write down how they knew about micro-organisms.

b. Phase 2

The second phase involved the same children, as Phase 1, in a more directed task, in which the children were asked to assemble a concept map about micro-organisms, using labelled photographs. It has been noted, in section 4.3.4, that concept maps have been used extensively in research including science education research and have employed a variety of different techniques. However, the use of photographs of items related to the research focus has not, as far as I am aware, been used before and it is, therefore, considered a novel aspect of the research presented here.

Children were provided with a page of named colour photographs (Appendix 4). They had been chosen because they had illustrated concepts about micro-organisms that children by the end of Year 9 should know. Additionally, the photographs were those that had most readily been recognised by children during the pilot study. The children were asked to look at the photographs and decide which of them had anything to do with micro-organisms and what that was. They were asked to stick the term micro-organism, or germ, which ever they preferred in the middle of an A3 piece of paper and then cut out their chosen photographs and stick them on the paper, draw a connecting line between the photograph and the term in the middle. They were asked to indicate what the association was, by writing why they had linked them. They were also encouraged to add additional links between the pictures if they could. Young children were able to ask their teacher, or me, what the names of the photographs were and to write down what they wanted to say, but no other help was given.

c. Phase 3

The third phase of data collection occurred approximately two weeks later. There were important reasons for this which I believed would have an impact on the outcome of the research. Firstly, the time lapse allowed the initial data to be scrutinised and children were selected for interview on the basis of this initial analysis, secondly the subject matter would not necessarily be fresh in the minds of the interviewees and the responses would not be influenced, or contaminated by the previous data collection methods. A sample of children from the original cohort of each age group was interviewed and the way in which the sample was chosen is discussed in section 4.4.1. The children who were chosen to be interviewed provided the opportunity to discuss ideas further and in more depth, acting as key informants (Denscombe, 1998), thus adding to the richness of the data already obtained in prior fieldwork.

I adopted the same interview procedures and protocols that were used during the pilot study and I noticed that it was easier to establish a rapport with each interviewee compared to the pilot study. The relative ease with which the interviews were conducted may be due to the fact that the children had already come into contact with me during the initial data collection phases and that I was known to them.

A one-to-one interview in the form of a multiple-method instrument was employed that included the use of 'props'. The 'props' were a mouldy peach, yogurt, bread, cheese and soy sauce as examples of foodstuffs that are manufactured with the aid of micro-organisms, and a photograph of a woman sneezing to initiate the discussion about disease, disease prevention and immunity. The interview schedule, which is adapted from the one used in the pilot study, can be found in

Appendix 2. The interviews were conducted in a quiet area away from the children's main classroom, with only the interviewee and I present in the room. All the interviews were tape-recorded and field notes were also gathered. The interviews lasted about thirty to forty minutes.

All the research methods employed during each phase of the field work were designed to elicit children's cognition of, rather than their attitudes towards micro-organisms, although at the end of each interview the children were invited to respond to an open-ended question about their feelings and attitudes towards and interest in micro-organisms. This was included; as it had been noted in the pilot study phase that several respondents had indicated revulsion and phobic attitudes towards micro-organisms and I was interested to develop this aspect of the research, although not as a main focus.

4.7 Data analysis

In order to begin to make sense of the information obtained during the field work, the data must be analysed. The notion that educational research can be identified as either qualitative or quantitative has been discussed in a Chapter 3. It has been acknowledged by many authors, (e.g. Robson, 1993; Denscombe, 1998), that such a simplistic distinction is too crude given the complexities of most research and that approaches are not mutually exclusive; the reality being that most researchers use parts of both approaches. A more useful distinction between what is regarded as qualitative and quantitative research lies with the treatment of data, rather than the methods used to obtain the information. Quantitative research relies upon numbers as the units for analysis, whilst qualitative research tends to be associated with words as the units of analysis (Denscombe, 1998). Data were analysed qualitatively and quantitatively and a description for each of the methods used in the research is provided below.

4.7.1 Drawings and brainstorms

White and Gunstone (1992) have reservations about qualitatively scoring drawings. They go on to suggest that attempting to quantify such a complex item as a drawing to a number, reduces the richness of the data and vitiates information. This was the stance taken here in analysing the drawings and the brainstorms, especially as both methods were entirely open-ended. Qualitative analysis was undertaken by attributing characteristics of the drawings and annotations to particular categories that emerged from studying the drawings and relating them to the categories that had emerged during the pilot study. The same categories were then applied to categorise the brainstorm statements. Quantitative tallying of the different categories was undertaken to provide frequency and percentage data for each category. A summary of the coding used, data from the drawings and brainstorms and examples of coding can be found in Appendix 3.

4.7.2 Photograph association concept maps

There is debate about using a criterion concept map to assess the maps produced by students; White and Gunstone (1992) consider it to be sensible practice, although more recently, critics have suggested that scoring against criterion concept maps is limiting (Yin *et al.*, 2005) and may provide skewed scores (Kinchin, 2000b). It was decided that a criterion map would not be used as a measure to compare the maps produced by the children, as the research wanted to capture all the data, rather than a selected, 'expert', view. The photograph association concept maps produced by the children were analysed qualitatively and quantitatively. The pre-selected photographs were used to illustrate several of the key themes that were foci of the enquiry. The propositions that children used with each photograph were assigned to a particular category. These propositions were further categorised and assigned a score. The purpose of this analysis was to provide an overview of what children know and understand about micro-organisms at three separate ages, rather than provide an assessment score for each individual and therefore, scoring procedures have been adapted from those found in the literature.

van Zele *et al.* (2004) note that a qualitative analysis of concept maps produced by university students studying physics provided a more informative and holistic picture of their understanding compared to quantitatively scoring the maps. White and Gunstone (1992) also have reservations about scoring concept maps. However, they offer an approach based on Novak and Gowin's (1984) system that has been adapted for use here and includes both qualitative and quantitative approaches:

- recording which photographs were chosen;
- recording all the propositions;
- categorising the propositions;
- recording absence of propositions or photograph;

Table 4.5
Scoring system for photograph association concept maps

Statement type	Score
Photograph not used / Photograph used without a statement	0
Non-scientific / alternative statement	1
Appropriate statements	2
More detailed / accurate statements	3
Advanced statements	4

Yin *et al.* (2005:168) state, that *'in order to characterise a student's map adequately more than a one dimensional scoring system is needed to evaluate the map comprehensively'.* Therefore, despite the reservations about quantitatively measuring children's knowledge and understanding from concept maps and the challenges posed in considering how they can be scored (Yin *et al.*, 2005), it was decided to score the number and accuracy of the propositions in the maps produced. The quality of the propositions, as well as their number, is an important aspect of this research, as this information will provide an insight into the depth of knowledge and understanding children have about micro-organisms and associated concepts. A scoring system, employing a five point scale (Table 4.5) similar to that used by Yin *et al.* (2005), was developed to provide an accuracy score for each photograph and therefore a level of the knowledge and understanding held by each year group. Other factors such as additional propositions and examples were also recorded.

Details of the criteria used to score each photograph are presented in Table 4.6 and frequency and percentage data were calculated for each photograph, on every map. A summary of the data from the concepts maps, examples of coding and completed concepts maps can be found in Appendix 4.

Recent research has explored the reliability and validity of scoring systems; (McClure *et al.*, 1999; Klein *et al.*, 2001; Kinchin, 2000b) and this research has sought to ensure that the scoring system adopted is both reliable and valid. The validity of the categories used to score each photograph was discussed with two experts separately. Agreement was reached about the accuracy of the scoring of each category for the different photographs. An inter-rater reliability exercise was undertaken on a 15% sample of all of the maps and, using Cohen's Kappa (Cohen, 1960) was found to be 0.78, indicating a satisfactory level of reliability. Full details of the inter-rater reliability exercise can be found in Appendix 5.

Table 4.6
Criteria used to score accuracy of propositions

Photograph	Scoring criteria
Sick child	1 = non scientific alternative statement; 2 = 'bad' micro-organisms / presence of micro-organisms / infected / infectious; 3 = cause illness; 4 = the effect of microbial activity in body / immune response to germs / micro-organisms
Vaccination	1 = non scientific alternative statement; 2 = prevents / protects / stops illness; 3 = micro-organisms / 'good' micro-organisms used in manufacture to prevent illness; 4 = dead / related less pathogenic micro-organisms used in manufacture to prevent illness; acquired immunity / immune response / antigen and antibody production
Antibiotics	1 = non scientific alternative statement; 2 = medication / stops illness; 3 = micro-organisms / 'good' micro-organisms used in manufacture to cure illness; 4 = effect on bacteria and fungal diseases only / not viruses
Bleach	1 = non scientific alternative statement; 2 = a cleaner / cleansing agent; 3 = affects / kills / stops micro-organisms; 4 = reduces number of micro-organisms / helps to prevent microbial growth / hygiene
Bread	1 = non scientific alternative statement; 2 = micro-organisms used to make bread / in bread; 3 = yeast used / present in bread; 4 = makes bread rise / activity of the yeast, carbon dioxide production
Beer	1 = non scientific alternative statement; 2 = micro-organisms used to make beer / in beer; 3 = yeast used / present in beer; 4 = fermentation to produce alcohol and or carbon dioxide
Yogurt	1 = non scientific alternative statement; 2 = micro-organisms used to make yogurt / associated with yogurt; 3 = bacteria used; 4 = fermentation / culture growth / effect on the milk
Mouldy bread	1 = non scientific alternative statement; 2 = micro-organisms present; 3 = microbial causation / mould is a micro-organisms; 4 = microbial / primarily fungal growth / microbial activity/bread used as a substrate
Sour milk	1= non scientific alternative statement; 2 = micro-organisms present; 3 = microbial causation; 4 = microbial growth / fermentation of milk / culture produced
Compost heap	1 = non scientific alternative statement; 2= contains micro-organisms; 3 = micro-organisms cause matter to decay; 4 = beneficial micro-organisms break down matter for use by other organisms / cycling of nutrients
Sewage works	1 = non scientific alternative statement; 2 = micro-organisms present; 3 = sewage processed / micro-organisms used to break down sewage / micro-organisms removed; 4 = beneficial micro-organisms break down organic matter in sewage and purify water helping to make it safe

4.7.3 Interviews

Attempting to score a semi-structured interview poses difficulties (White and Gunstone, 1992); especially when only a small percentage of the cohort is interviewed, making it difficult to make comparisons. The interviews obtained in this research project were used to enrich and qualify the data obtained from other methods. The interview transcripts were examined for statements that related to the key conceptual themes within this study; additional and supporting qualitative information was therefore made available. In addition, a numerical tally of how the statements related to the key themes was made, thus providing some quantitative information to support other findings. Examples of full interview transcripts, from Year 2, 6 and 9, can be found in Appendix 6.

4.8 Summary

This chapter has described and explained the research methods used within this study, including the development of a new concept mapping technique (CoMPAT). The suitability of the research methods for the wide age range is explained and a rationale for their use in addressing the research questions is provided. A discussion of the pilot study and how it influenced the main study is offered. How data were analysed qualitatively and quantitatively has been discussed and the findings from this analysis are discussed in detail in the following chapter.

Chapter 5

Findings

5.1. Presentation of findings

In this chapter, data collected using the research methods described in Chapter 4 are discussed in relation to the conceptual areas listed below and a summary of the key ideas is presented as a model for each age group. Progression of the ideas held by each age group is discussed, followed by an overview for each conceptual area. The findings are illustrated with examples of drawings, brainstorm comments, concept map propositions and excerpts from interviews. The examples were chosen to typify the ideas held by children in each age group and to be as representative as possible of the ideas elicited in this study. The conceptual areas discussed in the findings relate directly to those highlighted in Chapter 2. They are:

- o 5.2 classification;
- o 5.3 morphology;
- o 5.4 size and scale;
- o 5.5 the living and non-living state;
- o 5.6 disease, health and infection control;
- o 5.7 ecology and ecosystems;
- o 5.8 technological applications.

5.2 Classification

This section of the findings considers children's ideas about:

- o Grouping and variation of micro-organisms;
- o Terminology and its usage;

5.2.1 Grouping

Year 2

Data (Table 5.1) from drawings about the external appearance of micro-organisms shows that 7-year-olds consider micro-organisms to be cell-like, or animals, or abstract non-biological objects (Figures 5.1 and 5.2).

Table 5.1
Year 2: Grouping based on morphology of drawings n=159

Appearance / morphology	Percentage
Single cells / cell-like	19.1
Animals	54.7
Abstract	30.2
Other: complex abstract structures	5.7

Total may be more than 100% due to multiple drawings

The majority of drawings (54.7%) were of little animals, many anthropomorphised in some way, suggesting that micro-organisms are thought to actually be little animals, or to resemble little animals (Figure 5.1). Comments also confirm this point of view; for example, *'maggots might be germs'* (tb29); *'looks like a beetle'* (si42). Six out of the ten interviewees thought that micro-organisms were like animals and two children also thought that they could be both plants and animals. Reasoning appears to be based upon children's current knowledge of animals, with movement cited as the most common reason for suggesting micro-organisms are animal-like:

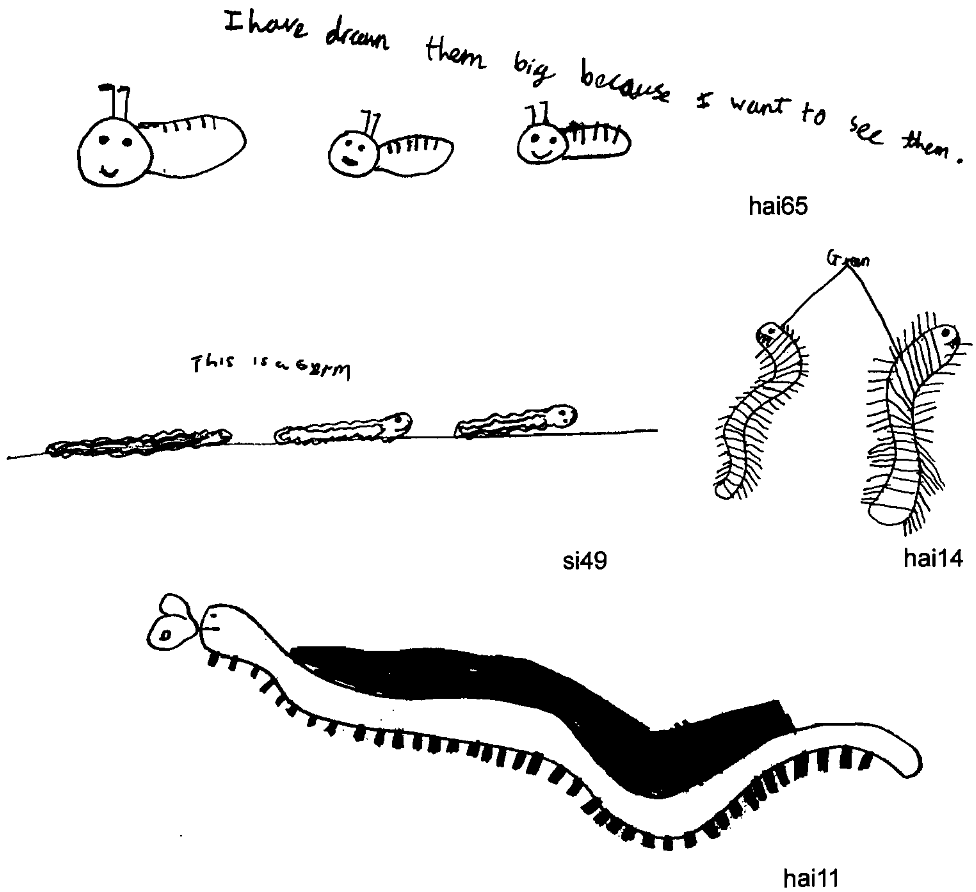
hai58 *Like um… have things that other animals like have, because some um, of some of the germs might have four legs, four legs, like animals have four legs. Some might, might jump like frogs jump and um, stuff. And like, some… Is it, some might fly, but not most.*

hai61 *I think um, they're sort of both.*
interviewer *Is there anything that makes you think that? That they're like plants and animals?*
hai61 *Because they're like an animal because they sort of can move and they've got a brain. And because I think they're plants is because um, they, I don't think they lay eggs, just like um, they don't lay their babies just like they're just popping out their tummy. I think they sort of lay these sort of seed things.*

Knowledge of plant life offers the previous child a reason for suggesting micro-organisms are plants and for another that micro-organisms are not plants:

si38 *They can't be plants.*
Interviewer *Why not?*
si38 *Because plants you can see and they're big and they grow and they have petals, which I don't think germs would have.*

Figure 5.1
Year 2: Animal-like drawings



Abstract drawings (Figure 5.2) were drawn by just over a third of children in this age group, suggesting that they do not associate micro-organisms with biological entities, but consider them as something different, as these children elaborate, *'germs are little bits of mud that get under your finger nail'* (hai34); *'I think germs look like dots'* (si43). Four out of the ten children interviewed consider that micro-organisms are neither plants nor animals, with one child indicating that they are akin to dirt, *'like little, little pieces of dirt'* (hai50). Other reasoning seems to be based upon the potential threat that micro-organisms pose to humans, *'they're not either…because plants and animals aren't as dangerous as germs'* (tb2); *'cause most animals can't make you ill'* (si9).

Figure 5.2
Year 2: Abstract drawings

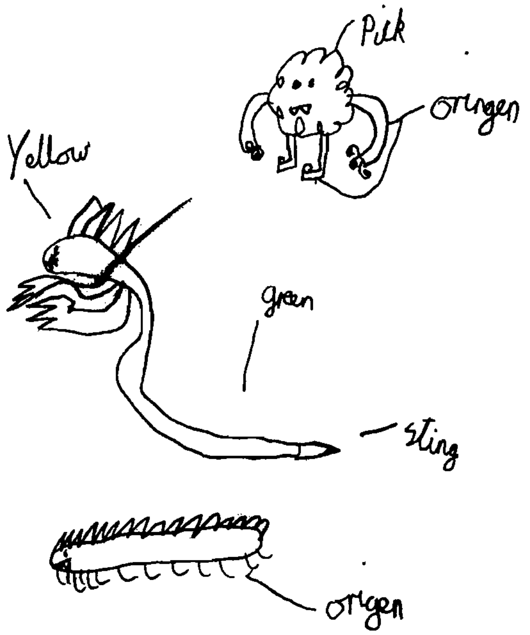
hai2

hai56

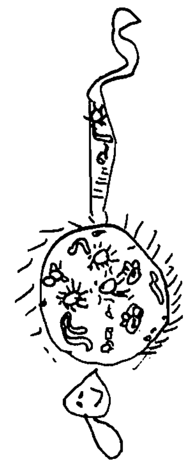
Drawings (Figure 5.3) and comments indicate that some children in this age group think micro-organisms vary; twelve drew a variety of 'germs' and four suggest, *'there are many different germs'* (si43), and half of the interviewees thought that micro-organisms would differ, *'well you know sort of like different sorts of animals, there can be sort of like be different types of germs as well.'* (si38). Two of the children interviewed based their reasoning on the effect micro-organisms have on human health rather than usual classification criteria:

hai61	*Um, well, um, some of them do different damages to us.*
Interviewer	*Mhm*
hai61	*Um, some cause different things and some cause the same things but they do it in, they do it in more harm. It's easier for them to kill.*

Figure 5.3
Year 2: Drawings to indicate microbial variation



hai15



tb6

Year 6

Table 5.2 shows the main groups, based on external appearance, that the Year 6 drawings were placed in. Over half the drawings (52.4%) were amorphous cell shapes, or like bacterial cells, which suggest that the majority of 11-year-olds consider micro-organisms as a distinct group of cellular organisms. Bacteria-like drawings accounted for 24.7 % of the total drawings, suggesting that 11-year-olds are more familiar with bacteria than other microbial groups.

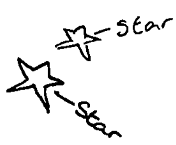
Table 5.2
Year 6: Grouping based on morphology of drawings n=166

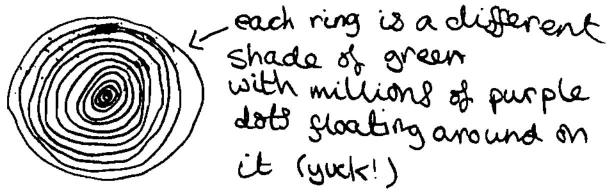
Appearance /morphology	Percentage
Single cells / cell like	52.4
Animals	31.3
Abstract	21.7
Other e.g. fantasy, complex structures	3.0

Total may be more than 100% due to multiple drawings

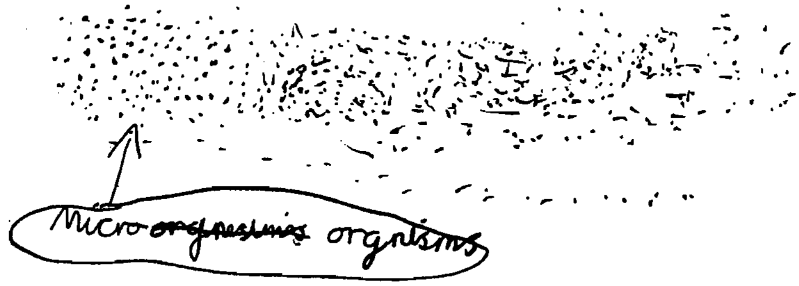
Just over one fifth of the drawings were abstract representations (Figure 5.4) and together with representations of 'cells' (Figure 5.5), it would seem that children do not consider micro-organisms to be plants or animals but something different and this is supported by the views of the interviewees. Seven of the eleven children interviewed thought that micro-organisms were not plants and six did not consider them to be animals either.

Figure 5.4
Year 6: Abstract drawings



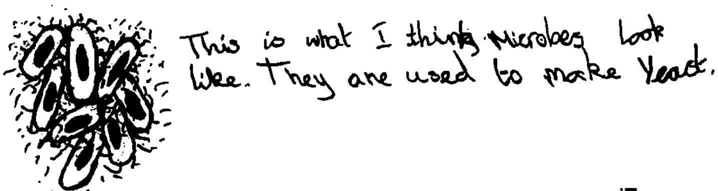


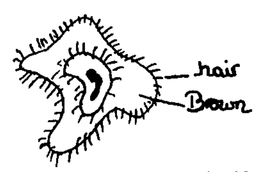
sm24 haj67



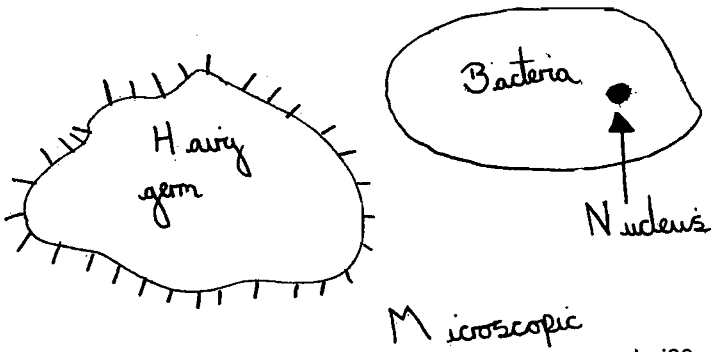
sm8

Figure 5.5
Year 6: Cell-like drawings





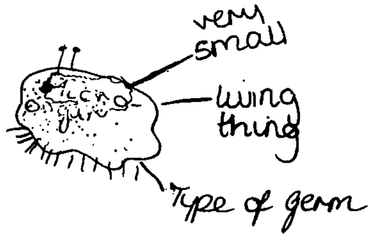
sj7 haj37



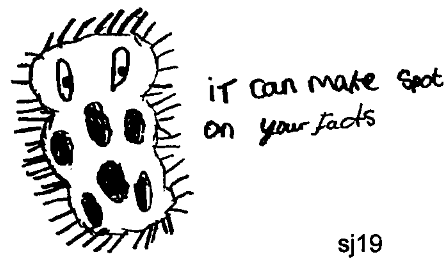
haj63

Two others suggested that micro-organisms are not plants or animals but were likened to plant or animal life, *'I think they're like a seed of a plant. I mean like, it can be moved easily and in like, quite a lot ways and it's so precious, like, if you had one it would be, and you could see it, it would be like, a once in a lifetime opportunity'* (sm31); *'Um, I wouldn't say they were animals, I'd say they're more like bugs. But, I don't think they're, I'm not sure about the plants in there. I think they can grow off plants… and then just like float away'* (haj12). Prior knowledge of seed and possibly spore formation seems to be used to make sense of how to classify micro-organisms by these children.

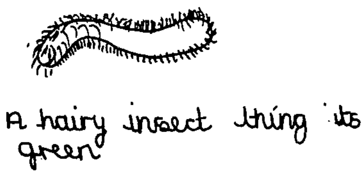
Figure 5.6
Year 6: Animal-like drawings



sm25



sj19



haj46

haj4

In contrast to the findings described above, just under a third (31.3 %) of the children drew animal like representations, many of which were anthropomorphised indicating that micro-organisms are thought to be animals or animal-like (Figure 5.6). Comments about the drawings support the notion that these children think that micro-organisms are like small animals *'it looks like a cockroach'* (sm24), or are actually animals, *'a hairy insect thing it's green'* (haj46). Two children interviewed thought that micro-organisms were animals and movement, or being alive, were given as reasons;

Interviewer	*Do you think that they're plants or animals?*
sj13	*Neither.*
Interviewer	*Why would you say that?*
sj13	*Cause um … Plants grow but microbes don't grow, well they might, but um I don't know. Um, what was the other one?*
Interviewer	*Are the things animals?*
sj13	*They might be animals cause they do move around.*

No child in this age group drew a micro-organism that resembled a plant, although during the interviews, fungi were thought to be either a plant or like a plant. Familiar fungal structures which children consider to be plant-like were used as reasons for this classification by two children:

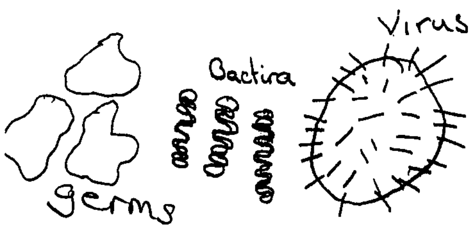
sj24	*Um, some of them are plants ……..fungi*
Interviewer	*Why?*
sj24	*Ah, 'cause they're like a mushroom'*
Interviewer	*And what about these other ones?*
sj24	*I think micro-organisms and germs, I don't think are plants or animals.*

The majority of Year 6 children do not consider micro-organisms as plants or animals but rather that they belong to a separate group. However micro-organisms are not considered to be a homogenous group, indicated by drawings (Figure 5.7), and comments, *'different sizes, different types'* (haj10); *'millions of different types'* (haj12), confirm this view. Interviews also revealed that children think micro-organisms vary:

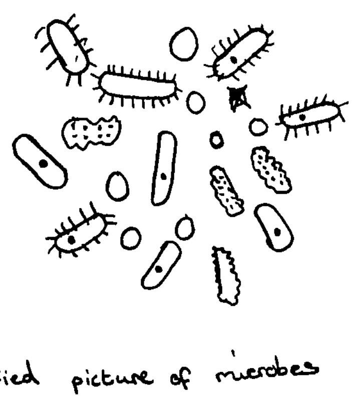
haj12	*Um, they come in many different sizes, shapes, colours and… They, they're different cause they do like different things. Some grow on like bread and stuff. Some just float round in the air. And water. Some give you diseases, some don't. Some help you… cure the diseases. But… they just do all different kinds of things.*
Interviewer	*Do you think they're actually different types?*
haj12	*Yeah.*

Four interviewees related this to the effect micro-organisms have on humans, in particular, whether they are thought to be harmful to humans, or not, rather than more usual classification criteria.

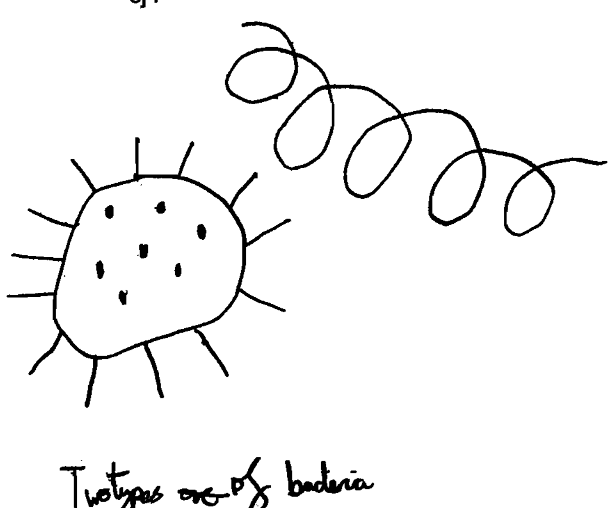
Figure 5.7
Year 6: Drawings to indicate microbial variation



sj4



sj12



sj9

Year 9

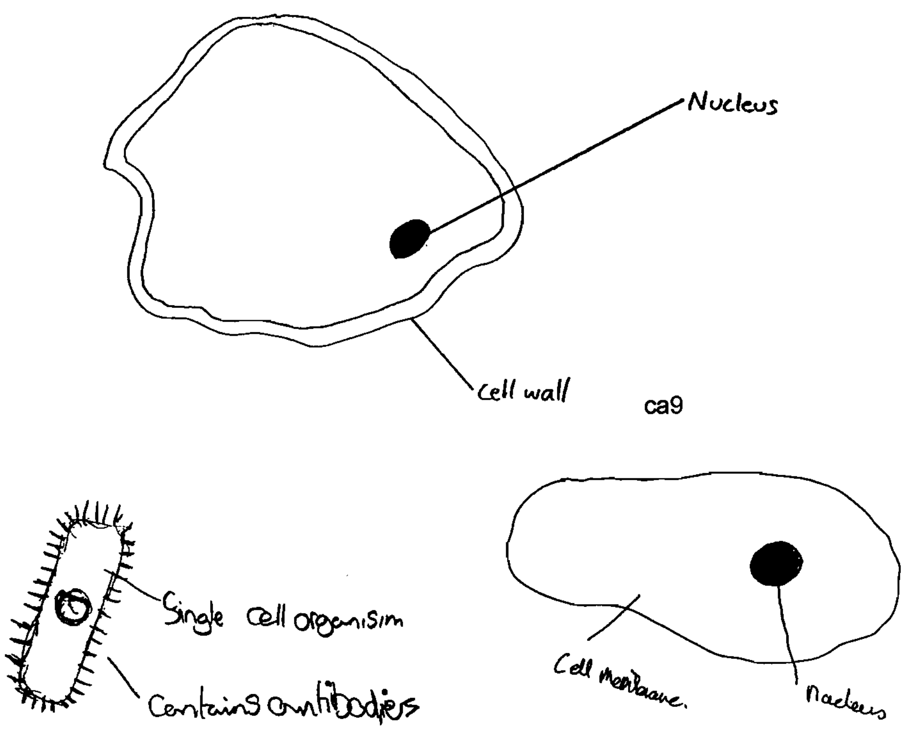
Drawings of the external appearance of micro-organisms were categorised into the groups shown in Table 5.3. Over half the drawings were of amorphous 'cell' structures and together with bacterial cell drawings they account for over 70% of all the drawings indicating that this age group generally consider micro-organisms to be single-celled organisms and different from multi-cellular plants and animals (Figure 5.8).

Table 5.3
Year 9: Grouping based on morphology of drawings n=89

Appearance / morphology	Percentage
Single cells / cell like	70.9
Animals / anthropomorphic	19.1
Abstract	15.7
Other e.g. sperm, animal, plant cells	12.4

Total may be more than 100% due to multiple drawings

Figure 5.8
Year 9: Cell-like drawings



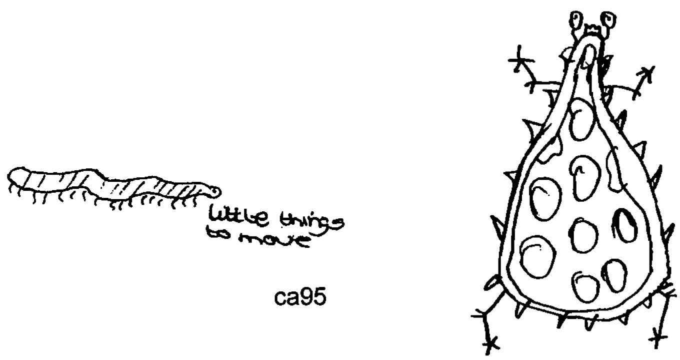
However, prior knowledge of eukaryotic cells was evident in some drawings (12.4%) and annotations referred to plants and animals *'like a plant cell'* (ca100); 'an *animal cell'* (ca67). There also appears to be some confusion about whether micro-organisms are simply a single plant or animal cell or something different:

ca18	*Aah, that's some kind of micro-organism and I can't remember what it was. … um, has a cell, I think it, yeah, it's got cell walls so it's probably a plant cell of some description. Oh! I know what it is. OK, no I don't.*
Interviewer	*So, are micro-organisms plants?*
ca18	*Aah, no they're basically just made out of cells which ah, micro-organisms are made out of, but they're just… Basically, you could imagine it in a way that plants are made out of millions of micro-organisms, in a way.*

A noteworthy minority of children (19.1%) drew either animal-like or anthropomorphic drawings (Figure 5.9) indicating that micro-organisms were akin to animals in some way. Four of the nine interviewees thought the micro-organisms were animals or animal-like with movement or being alive given as reasons for their ideas:

ca94	*No, I don't know, I don't think so just 'cause, I'd say they're like animals, cause they're like living things and they move like, different places'.*

Figure 5.9
Year 9: Animal-like drawings



ca95

ca7

Three interviewees also considered that micro-organisms, especially fungi could be plants, although no reasons were offered, whilst uncertainty about what micro-organisms are, is apparent:

ca18	*Um, if it's a fungus then it's probably going to be plant life. Ah…*
Interviewer	*Why?*
ca18	*Because, I don't know. Ah, if they're viruses um, I honestly don't know again. Ah, bacteria are also most likely to be plant like but again I don't know.*

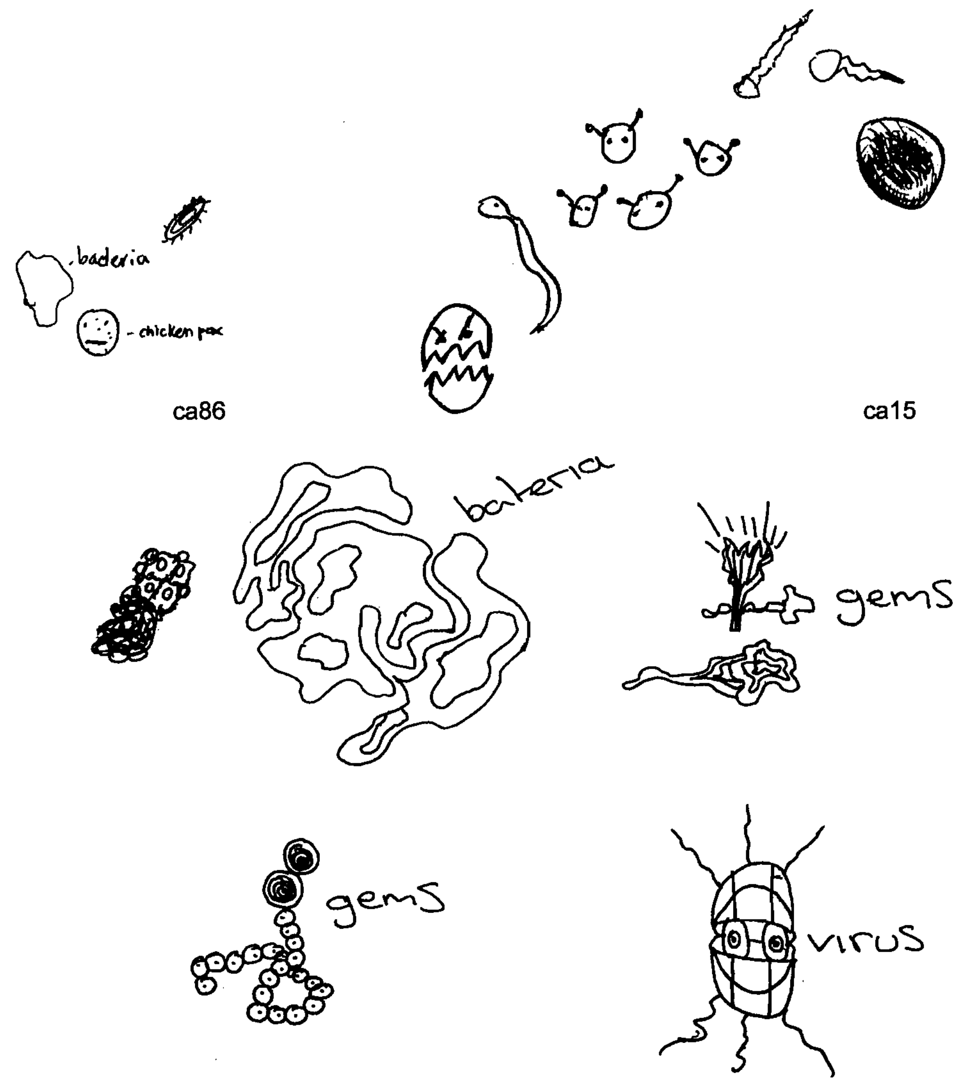
Others seem to be equally confused about how they would classify micro-organisms:

ca78	*Um, I think they're maybe animals.*
Interviewer	*Why would you say that?*
ca78	*'Cause they like, they're alive and they're not humans. They could be aliens, but I don't think so'.*
ca23	*Um, the micro things like can, sort of like cells and dust like, bacteria and stuff, like, bacteria's like a little cell and stuff…… different type of cells. And um, I did like, little like, little particles to show the thing, the micro things. The atoms and particles and stuff.*

Micro-organisms are considered by the majority of this age group to be single cells; however, drawings (Figure 5.10) indicate that children in this age group consider that a variety of micro-organisms exist. Interviews also revealed that a variety of micro-organisms are thought to exist and variation is determined by what the micro-organisms do and the extent of harm to humans is a key classification criterion:

ca89	*Um, they all like, make you ill.*
Interviewer	*Are they the same thing, or different?*
ca89	*Different, 'cause some are like, more deadly than others.*
Interviewer	*And which ones are more deadly than others?*
ca89	*Um… virus.*

Figure 5.10
Year 9: Drawings to indicate microbial variation



ca86 ca15

ca55

5.2.2 Terminology and its usage

Year 2

The term 'germ' was universally used by those children who made reference to a named micro-organism in their brainstorms and only 6.9% of children referred to any other term on drawing annotations (Table 5.4). Alternative names were exclusively linked to invertebrate animals, for example, ants, insects, and fleas. Interviewees were uncertain about other microbial terms, *'Well I've heard of the word but I'm not sure what a virus is'* (si38), and only when prompted did some children indicate that they had heard of any other terms, as this exchange shows:

Interviewer	*Have you ever heard of any different kinds of germs?*
tb29	*No*
Interviewer	*So, Have you ever heard of bacteria?*
tb29	*I think I have but I've never really learned about it.*
Interviewer	*That's OK. What about viruses?*
tb29	*I've only, I've heard of virus from my brother's police station game on Scoobie Doo.*
Interviewer	*What about fungus?*
tb29	*No.*
Interviewer	*What about um, the word micro-organism?*
tb29	*Maybe, maybe not.*

Table 5.4
Year 2: Terms used in drawings and brainstorm
(n=159 drawings, n=139 brainstorms)

Name	Percentage of drawings	Percentage of brainstorms
Micro-organism / microbe	0	0
Germ	31.4	83.5
Bacteria	0	0
Virus	0	0
Fungi / mould	0	0
Several terms used	0	0
Specific	0	0
Other - Animal	6.9	0

Total may be more than 100% due to multiple terms used

Different terms were so rarely employed by this age group it is difficult to make any comment about children's knowledge of different microbial groups, or how they are connected.

Year 6

Most children either labelled their drawings 'a micro-organism' (38.6%), or used the term in their brainstorms (82.9%); this is not surprising as this was the term used in the instructions given to complete the tasks. However, the terms 'germ', 'bacteria' and to a lesser extent 'virus' and 'fungi' were also used (Table 5.5).

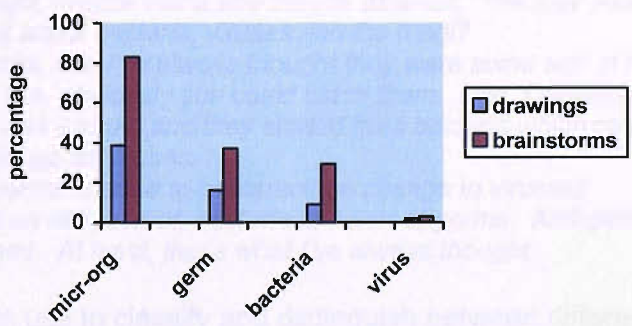
Table 5.5
Year 6: Terms used in drawings and brainstorms
(n=166 drawings, n=164 brainstorms)

Name	Percentage of drawings	Percentage of brainstorms
Micro-organism / microbe	38.6	82.9
Germ	16.1	37.2
Bacteria	9.0	29.3
Virus	1.8	3.0
Fungi / mould	0	2.4
Several terms used	10.8	54.2
Specific e.g. yeast, salmonella	0.6	7.9
Other – Animal	1.8	1.2

Total may be more than 100% due to multiple terms used

Whilst the frequency of these terms differed in the drawings and brainstorms, Figure 5.11 shows that the pattern of usage was similar in both instances. Yeast was the most commonly referred to specific micro-organism. During interviews, all except one child, who also mentioned viruses, talked about micro-organisms, germs and bacteria and only when prompted did they say that they had heard of other micro-organisms such as fungi and viruses. These findings indicate that children of this age are more familiar with the terms 'micro-organism', 'germ' and 'bacteria' compared to 'virus', 'fungi' or specific names other than yeast.

Figure 5.11
Year 6: Terms used in drawings and brainstorms



More than one term was employed by some children in labelling their drawings and in the brainstorm information (Table 5.6). Terms were used in two distinct ways, some children labelled their drawing using several terms, indicating that 'micro-organism' and 'germ' were generic names for all micro-organisms and were used interchangeably, *'this is a micro-organism also can be called a germ'* (sj38); *'non scientific name is germs'* (sj9). Bacteria were also frequently included as a generic term, *'sometimes called bacteria'* (sj31); *'other names are bacteria and germs'* (sj2).

Table 5.6
Year 6: Usage of multiple terms in drawings and brainstorms
(n=18 drawings, n=89 brainstorms)

	Percentage of drawings	Percentage of brainstorms
terms used interchangeably	27.8	69.6
terms used independently	72.2	30.4

Other usage indicated that micro-organisms and germs are different and different from bacteria, viruses and fungi, *'some microbes have germs'* (sj6); *'some are germs some are bacteria'* (haj4); *'can be germs, can carry diseases or viruses'* (haj61). Some comments suggest that micro-organisms are the genesis for other types, *'large microbe with small bacteria inside it'* (haj33); *'microbes cause viruses'* (sj8); *'they are bits of bacteria'* (haj1), suggesting that micro-organisms are a super-ordinate group which can develop into other types of micro-organisms. These comments indicate that children have confused ideas about the terms used to identify different micro-organisms and the connection between them, as this interview illustrates:

sm31	*Well, um... germs and micro-organisms, I've always thought were quite similar because um, in a way, I've always thought that germs and micro-organisms looked like each other and they were a part of each other, like, micro-organisms were a part of germs. So like, they travel together. Because, wherever you've got bad micro-organisms you all, obviously got germs, good ones as well. Like um, everyone's got germs, obviously different ones 'cause they're different people and well, and that's why I thought, maybe that's why they're different. The way your body's made.*
Interviewer	*What about bacteria, viruses and the fungi?*
sm31	*Viruses, um, I've always thought they were some sort of like, a disease. And like, obviously you could catch them. Like, I've always thought chicken pox was a virus, and they started from bacteria which came to germs and ended up as viruses.*
Interviewer	*So germs change to bacteria then change to viruses?*
sm31	*No they like, sort of, bacteria is a part of germs. And germs contribute to viruses. At least, that's what I've always thought.*

The names children use to classify and distinguish between different microbial groups seem to be an area of confusion. 'Micro-organism', 'germ' and 'bacteria' are the most commonly recognised terms by this age group, and even though some children understand that, 'micro-organism' and 'germ' are generic terms their usage is frequently confused indicating that the terms and what they refer to are not clearly understood.

Year 9

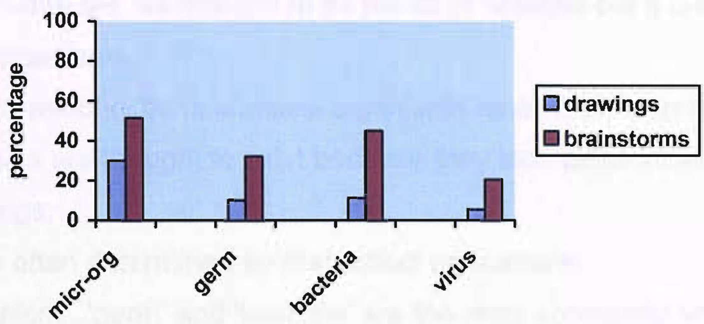
Children in this age group are aware of a variety of microbial terms (Table 5.7), 'bacteria' was more commonly used than 'germ' and the overall pattern of responses in the drawing and brainstorms (Figure 5.12) indicate that 'micro-organism', 'germ' and 'bacteria' are the names that children in this age group are most are familiar with. 'Virus' is more frequently used by this age group compared to Year 2 and 6 and 'fungi' is the least cited by this age group. The most common specific name used was 'yeast'.

Table 5.7
Year 9: Terms used in drawings and brainstorms
(n=89 drawings, n=78 brainstorms)

Name	Percentage of drawings	Percentage of brainstorms
Micro-organism	30.0	51.3
Germ	10.1	32.1
Bacteria	11.2	44.9
Virus	5.6	20.5
Fungi / mould	0	1.3
Several terms used	10.1	52.6
Specific e.g. yeast, algae, amoeba	2.2	23.1
Other e.g. sperm cell	9.0	12.8

Total may be more than 100% due to multiple terms used

Figure 5.12
Year 9: Terms used in drawings and brainstorms



Several terms were used in two separate ways, 'micro-organism' was used as the generic term for all micro-organisms by most children, *'micro-org is the name' [for all]* (ca39); *'all different things, they're like from the same sort of family but they all do different things'* (ca62). Germs and bacteria were not used as frequently as generic terms and were more often regarded as types of micro-organisms, *'bacteria eats all white blood cells, they.... make you feel ill with all the germs'* (ca78).

Table 5.8
Year 9: Usage of multiple terms in drawings and brainstorms
(n=9 drawings, n=41 brainstorms)

	Percentage of drawings	Percentage of brainstorms
terms used interchangeably	55.6	97.6
terms used independently	44.4	2.4

How terminology is used and what the terms refer to seems to be an area of confusion, *'Um, I think the bacteria, viruses and fungi are sort of, types of germs and bacteria. Um, but I don't think, I think m, molecules, micro-organisms, sorry, I think they're sort of like um, a type of process maybe, with all those things'* (ca23). 'Micro-organism', 'germ' and 'bacteria' are the most commonly recognised terms by this age group, although some children seem to be confused about the terminology used to identify micro-organisms and what it refers to.

5.2.3 Summaries, progression and overview

A résumé of the findings about grouping of micro-organisms, terminology and its usage in relation to micro-organisms is presented below.

Year 2

- Micro-organisms are thought to be either little animals or non biological entities;
- 'Germ' is the only commonly known term;
- Different types are thought to exist because they look different and do different things;
- Harm done to human health is considered as a key differentiating criterion.

Year 6

- Micro-organisms are not thought to be plants or animals but a distinct group of cell-like organisms;
- A substantial minority think of micro-organisms as animals or animal-like;
- Different types are thought to exist because they look different and do different things;
- Grouping is often determined by their effect on humans;
- 'Micro-organism', 'germ' and 'bacteria' are the most commonly known terms;
- 'Micro-organism', 'germ' and 'bacteria' are used generically;
- Terminology is frequently used in a confused manner indicating the terms and what they represent is not thoroughly understood.

Year 9

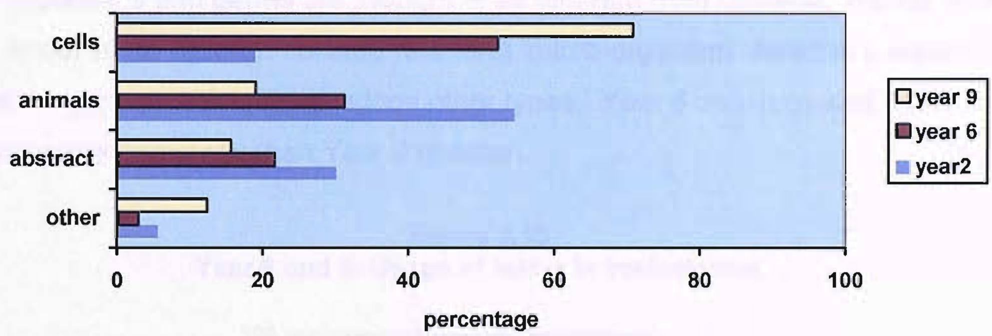
- Micro-organisms are thought to be single celled organisms;
- Micro-organisms are frequently associated with the cells of eukaryotic organisms;
- A substantial minority consider micro-organisms to be plants and animals or like a plant or animal;
- Different types are thought to exist because they look different and do different things;
- Grouping is often determined by the effect on humans;
- 'Micro-organism' and 'bacteria' are the most frequently used terms but virus and fungi also known;
- Terminology used in a confused manner by some children indicating the terms and what they represent is not thoroughly understood.

Progression

Grouping and variation

Data from external appearance of drawings (Figure 5.13) and interviews indicates that a more accurate classification of micro-organisms seems to develop with age. The number of children that regard micro-organisms as single cells increases with age, whilst the number that consider them to be animals or animal-like decreases in a similar manner. However, a substantial proportion of older children retain the idea that micro-organisms are animals, although this does decrease between Year 6 and Year 9. Many of the older children also regarded all microbial cells akin to cells of eukaryotic organisms. The number of children who consider micro-organisms as non-biological entities also decreases with age.

Figure 5.13
Year 2, 6 and 9: Groupings based on morphology of drawings



All age groups consider that micro-organisms vary in appearance and in their activities. It is interesting to note that a key criterion for all age groups in determining how micro-organisms vary is the effect they have on humans, in particular if they are harmful or not and indicates anthropocentric thinking.

Terminology and usage

The range of terms used to refer to micro-organisms increases with age. Year 2 children used 'germ' exclusively when talking about micro-organisms and the older age groups used a variety of terms. Figure 5.14 shows the terms used in brainstorms; 'virus' and 'bacteria' are used more frequently and 'germ' is used less frequently by older children, indicating a growing awareness of different types of micro-organisms.

Figure 5.14
Year2, 6 and 9: Terminology used in brainstorms

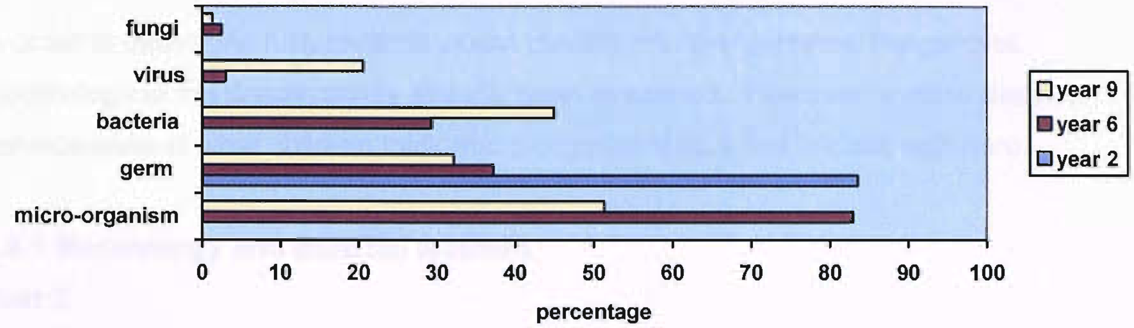
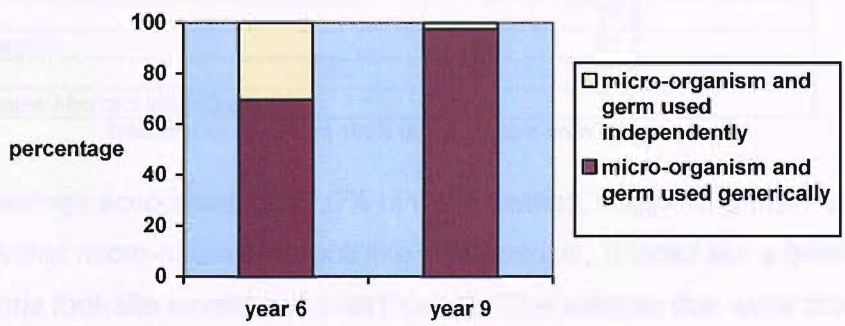


Figure 5.15 shows that the terms are used in two distinct ways by Year 6 and Year 9 children. 'Micro-organism' and 'germ' are used as generic terms for all others and these terms are used interchangeably; Year 9 children also seem to be more aware that these are generic terms. A second mode of usage appears to indicate that micro-organisms and germs are thought of as different from bacteria, viruses and fungi, whilst some children consider the term 'micro-organism' denotes a super-ordinate organism which can produce other types. Year 6 children used terms in this way more frequently than Year 9 children.

Figure 5.15
Year 6 and 9: Usage of terms in brainstorms



Overview

Classification of micro-organisms becomes more accurate with age, although some ideas seem resistant to change, for example, the connection with micro-organisms and animals. 'Germ' is the only term used by the youngest children to refer to micro-organisms. A greater variety of terms is used by Year 6 and Year 9, but the inconsistent usage indicates confused thinking about different types of micro-organisms. Micro-organisms are not thought to be a homogenous group; they are thought, by all age groups, to vary in their appearance and activities. However, anthropocentric thinking is apparent in all age groups, as the effect that micro-organisms have on human health is used as a key criterion for microbial variation.

5.3 Morphology

In order to determine how children would classify micro-organisms, the general morphology of the drawings has already been examined. However, a more detailed consideration of what children think micro-organisms look like is dealt with here.

5.3.1 Morphology and external features

Year 2

Annotations of drawings suggest that this age group has a variety of ideas about what micro-organisms look like, *'they're big blobby things and sometimes they're round'* (hai21); *I think germs look like little bubbles'* (si35); *'slimey, watery, gooey, drippy'* (si9); *'I think germs look like dots'* (si43). Analysis of the drawing types (Table 5.9) show that abstract drawings were the most commonly drawn single category and geometric shapes such as circles, rectangles, or lines, were the most common (74.1%) within this category.

Table 5.9
Year 2: Morphology of drawings n=159

Appearance /morphology	Percentage
Amorphous	12.8
Bacterial Cell	6.3
Animal like	27.0
Anthropomorphic	27.7
Abstract	30.2
Other -complex abstract structures	5.7

Total may be more than 100% due to multiple drawings

Animal-like drawings accounted for 27.0% of the drawings, suggesting that many 7-year-olds think that micro-organisms look like little animals, *'it looks like a beetle'* (si42); *'my germs look like worms but it isn't'* (si44). The animals that were drawn tended to be invertebrates and worms, or caterpillars were the most common (Table 5.10). These children consider that micro-organisms look like small animals and they relate them to the species with which they are familiar (Figure 5.16).

Table 5.10
Year 2: Types of animal like drawings n=43

Types	Percentage
Insects	30.2
Tadpoles	4.7
Worms / caterpillars	37.2
Other e.g. Frog, snail ,cartoon	32.6
Anthropomorphised drawings	79.1

Total may be more than 100% due to multiple drawings

Figure 5.16
Year 2: Types of animal-like drawings

hai24 tb7 tb13

Twenty eight (17.6%) animal drawings were anthropomorphised and a further 27.7 % drew a little person (Figure 5.17). Facial features were the most commonly represented anthropomorphic feature especially eyes and a mouth.

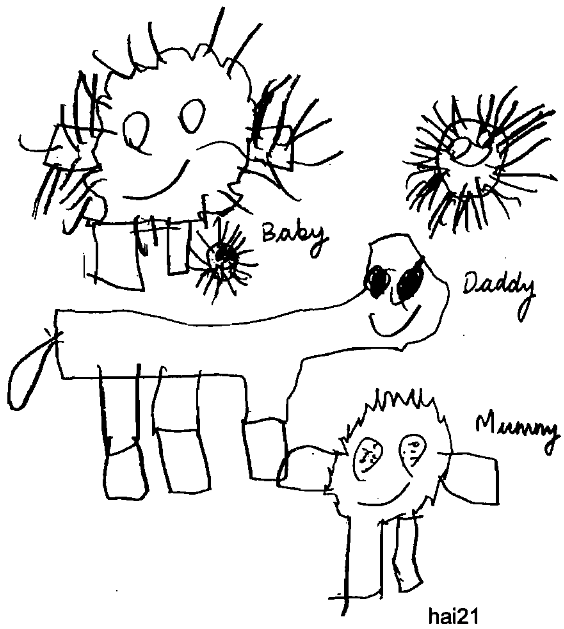
Some children drew an amorphous cell (12.8%), or a recognisable bacterial cell shape (6.3%), and the bacillus shape was the most commonly drawn bacterial cell (Figure 5.18). This would suggest that a small proportion of this age group know that micro-organisms are single celled, although further knowledge of their morphology, or the variety of external structure is not apparent.

Table 5.11
Year 2: External features of drawings n=159

External features	Percentage
Hairs	10.7
Tail	6.3
Facial features	49.1
Legs	27.7
Arms / hands / wings	17.0
Head	12.6
Spikes	2.52
Tentacles/antennae	9.4
Colour	16.4
None	31.4

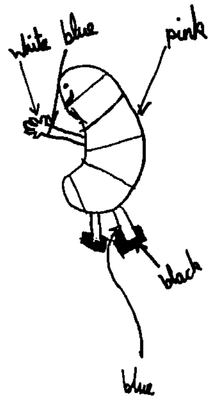
Total may be more than 100% due to multiple features on drawing

Figure 5.17
Year 2: Anthropomorphised drawings

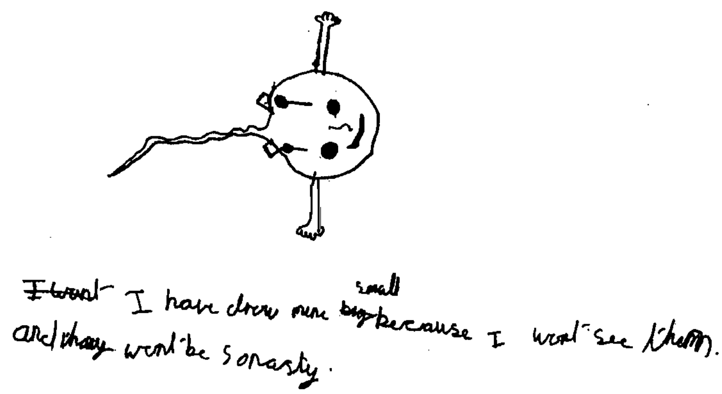


hai21

tb28

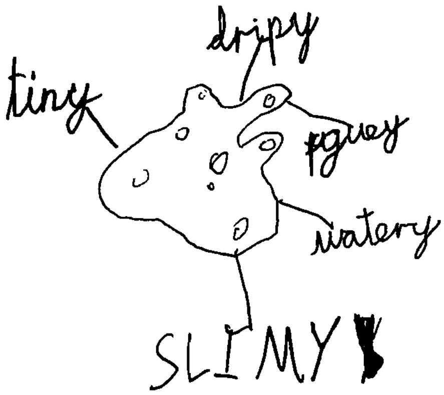


hai50



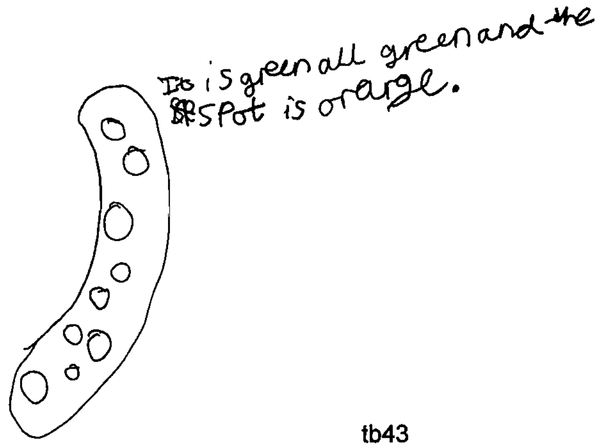
hai43

Figure 5.18
Year 2: Amorphous and bacterial cell drawings



si9

hai61

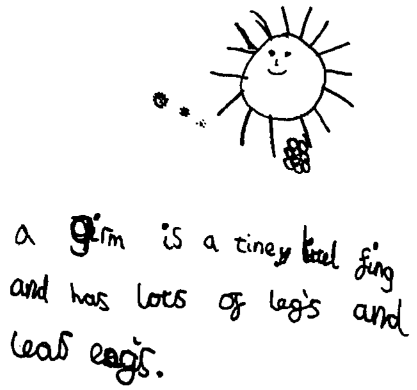


tb43

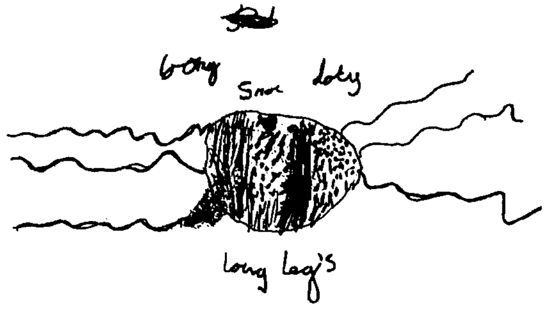
A variety of external features were represented on the drawings (Table 5.11), facial features and limbs associated with animal-like and anthropomorphic characteristics were most common (Figure 5.19). Annotations tended to label the features rather than explain their function, for example, '*eyes, 18 legs, nose mouth*' (hai51); '*a germ is a tiny little thing and has lots of legs and lays eggs*', (hai59).

The colour of micro-organisms was also a common feature although, no particular colour was noted and some annotations included a wide range of colour, '*I think my first germ has blue eyes, red nose, a orange tummy, yellow mouth, green antennae and yellow legs*' (hai46).

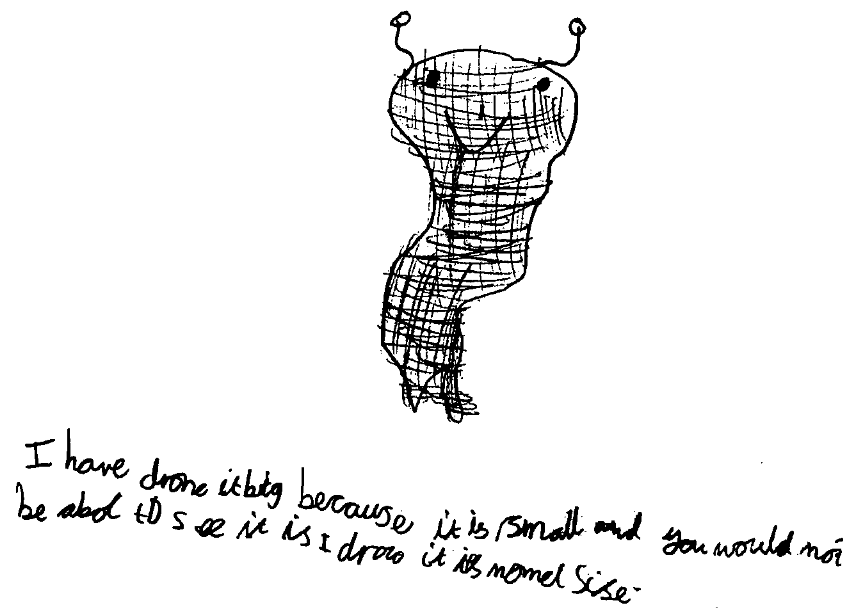
Figure 5.19
Year 2: External features



hai59



hai73



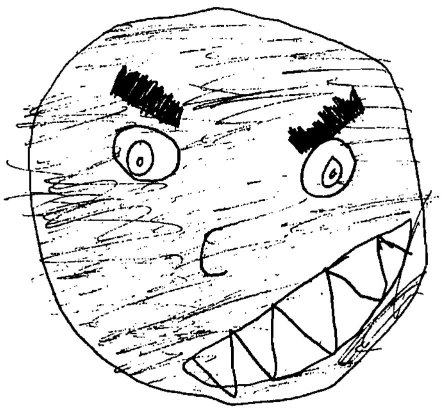
hai58

Harmful

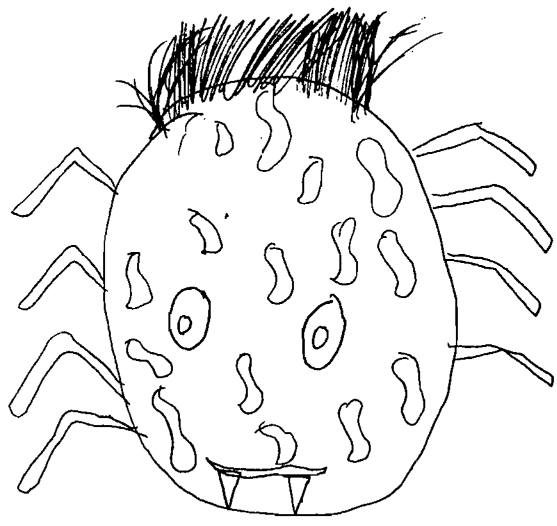
Cartoon-like drawings were common (22.0%) and several (10.7%) look like little monsters having sharp teeth, claws, or a tail with a sting in it (Figure 5.20). Cartoons are not surprising given the portrayal of micro-organisms in the media, such as television advertising, which often depicts micro-organisms as little animals or monsters. Other drawings indicated that this age group considers micro-organisms to be harmful, for example, associated with a harmful animal such as a snake or with activities such as smoking.

Figure 5.20
Year 2: Cartoon-like drawings

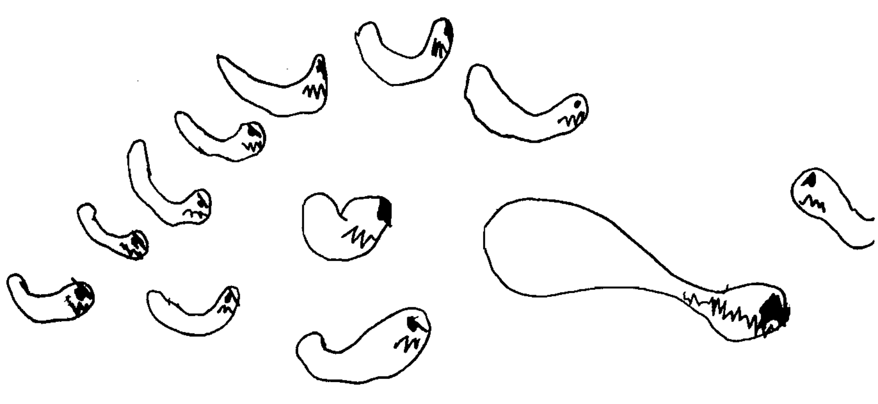
si1



hai72



hai60



si10

Annotations add to this perspective, *'it wouldn't have a smiley face because they're not friendly'* (hai6), and indicate an aversion to micro-organisms, *'when I drew this* *picture I shivered as I drew more and more germs'* (tb33). The following description of this child's drawing indicates anthropocentric thinking in relation to her negative attitude towards micro-organisms:

hai50	*Um, well, it crawls all over us and um, and it kept spitting at us, all over our body. It was little, titchy and they went in herds. And some of them had um, brown hats on.*
Interviewer	*What sort of things do they do?*
hai50	*Well, they came along and they had lots of dirty, horrible stuff in with the people, in with their hats and then they took their hats off and let the dirty horrible stuff was all inside it and then they just chucked it all around us.*
Interviewer	*And what do you think they'd be like inside?*
hai50	*Um, hollow.*
Interviewer	*Would there be anything inside the body?*
hai50	*Um...Little cold heart.*
Interviewer	*And why would it be cold?*
hai50	*Cause they're nasty.*

Year 6

Ideas about external appearance vary widely and include scientific representations, as well as imaginative fantasy drawings (Table 5.12).

Table 5.12
Year 6: Morphology of drawings n=166

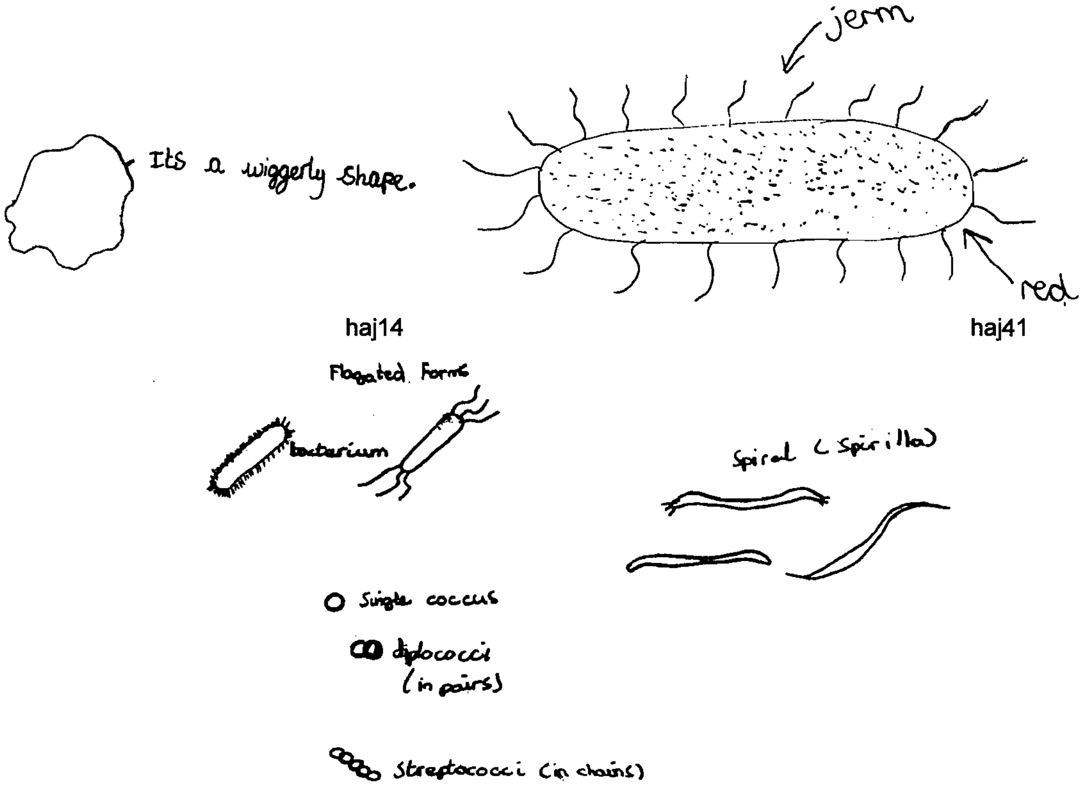
Appearance /morphology	Percentage
Amorphous	27.7
Bacterial Cell	24.7
Animal like	21.1
Anthropomorphic	10.2
Abstract	21.7
Fantasy/ Complex	3.0

Total may be more than 100% due to multiple drawings

Drawings connected to aspects of biological organisms (Figure 5.21) indicate that just over half of the children (52.4%) have some notion that micro-organisms are single-celled, although many do not have a clear understanding of their morphology, as these comments suggest, *'squashy, stuck together'* (sj56); *'no particular shape'* (haj23). However, 24.7% drew a recognisable bacterial shape (rod, coccus or spiral) and the bacillus was by far the most commonly drawn shape (16.3%). Some children within this age group appear to have some knowledge of the general categories of bacterial morphology with the bacillus as the most commonly recognised. The shape of bacteria compared to other micro-organisms, such as viruses, or fungi, may be more familiar to these children from photographs or drawings in school texts and reference books, or posters in doctors' surgeries, hence the absence of other microbial drawings.

Figure: 5.21

Year 6: Amorphous and bacterial cell drawings



haj14 haj41

haj12

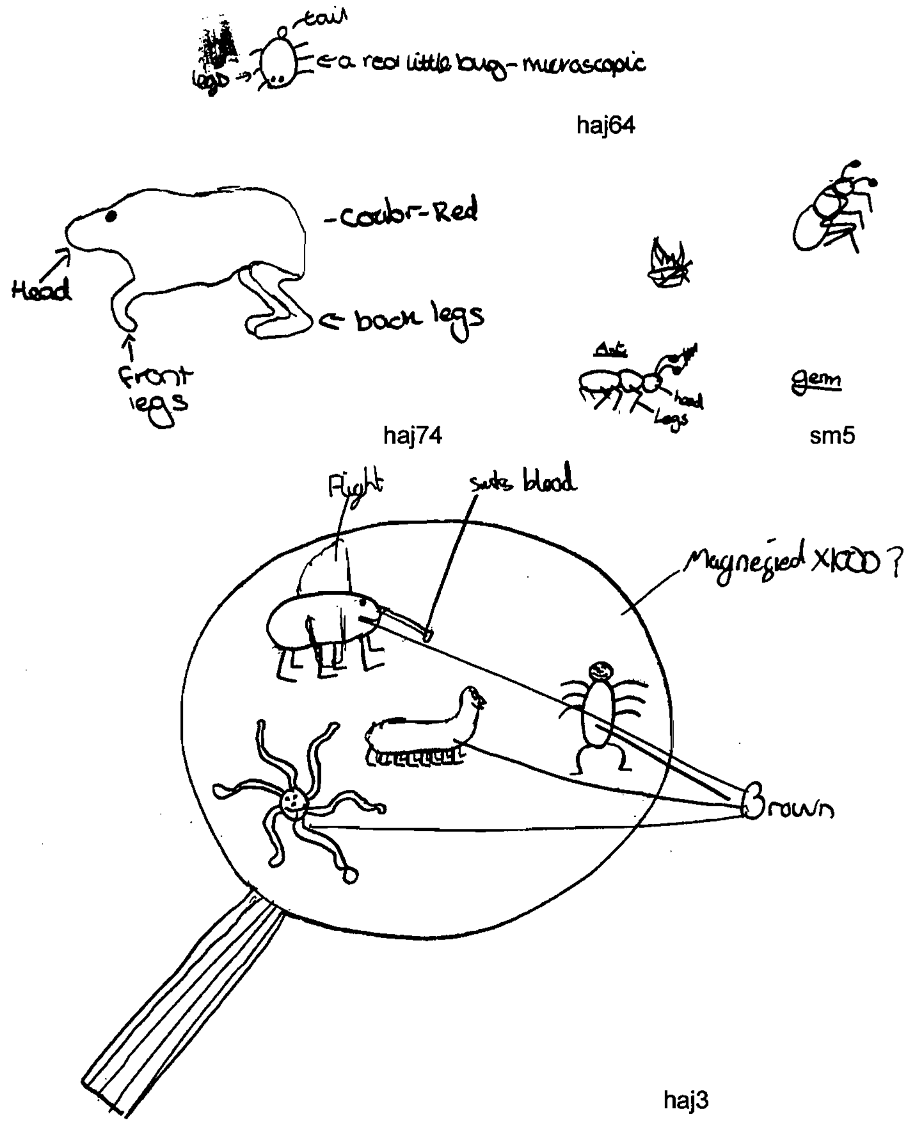
Other drawings indicate association with other biological species, animal-like drawings were provided by 21.1% indicating that these children think that micro-organisms look like small animals, '*I think they are worm shaped creatures*' (sj21). Invertebrates were the most commonly represented (Table 5.13) and almost half of the animal-like drawings were of some kind of insect (Figure 5.22). Other drawings included a frog and cartoon-like animal shapes. These children would appear to have some ideas that micro-organisms are small living things that look like the small animal species with which they are familiar.

Table 5.13
Year 6: Types of animal-like drawings n=35

Types	Percentage
Insects	48.57
Tadpoles	22.85
Worms / caterpillars	11.42
Other e.g. Frog, cartoon	17.14
Anthropomorphised drawings	37.14

Total may be more than 100% due to multiple drawings

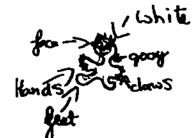
Figure 5.22
Year 6: Types of animal-like drawings



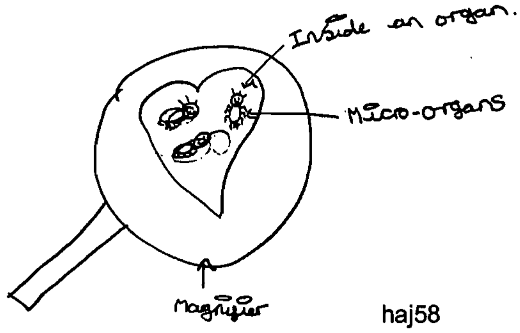
Thirteen (7.8%) of the animal-like drawings were anthropomorphised in some way, for example, providing human facial features (Figure 5.23). A further 10.2% of this age group drew an anthropomorphised version of a micro-organism, often appearing cartoon-like. Television adverts, cartoon programmes and other sources seem to have influenced these drawings.

Figure 5.23
Year 6: Anthropomorphised drawings

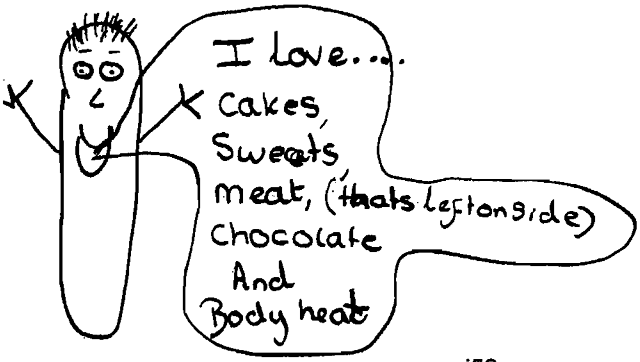
haj32



haj52



haj58



sj52

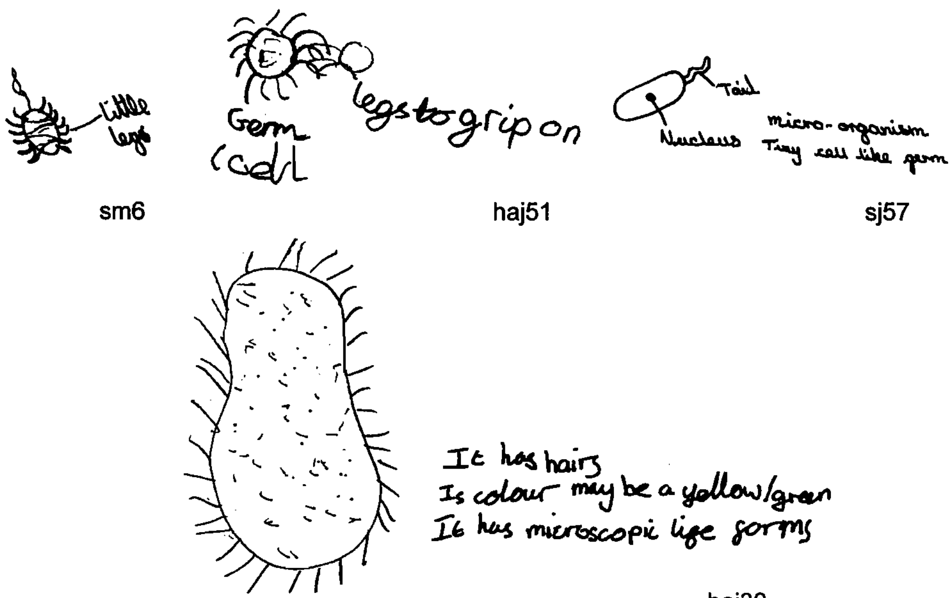
Many of the drawings (Figure 5.24) included external features, which are associated with animal-like or anthropomorphic characteristics, for example hairs or a tail (Table 5.14). Annotations on the drawings provided reasons for their presence which indicates anthropocentric and teleological reasoning, *'there is a tail so it can swim through blood and skin'* (haj44); *'tiny eye to see where it's going'* (haj39). Colour was also commonly included, although no specific colour seems to be particularly associated with micro-organisms.

Table 5.14
Year 6: External features of drawings n=166

External features	Percentage
Hairs	35.5
Tail	6.0
Facial features	18.7
Legs	15.7
Arms/hands/wings	5.4
Head	8.4
Spikes	4.2
Tentacles/antennae	6.6
Colour	20.5
None	31.3

Total may be more than 100% due to multiple features on drawings

Figure 5.24
Year 6: External features



sm6 haj51 sj57

haj30

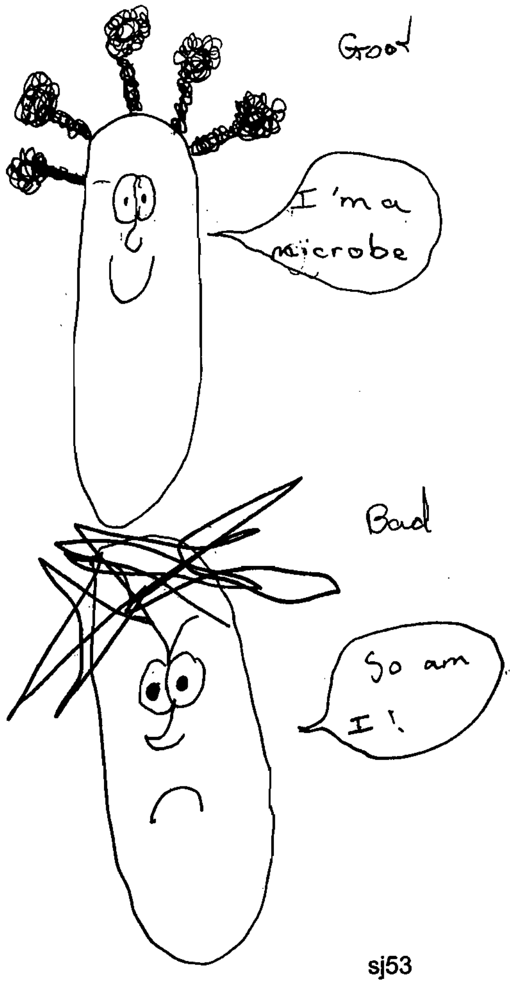
Just over one fifth (21.7%) of the children drew an abstract picture; the majority drew geometric shapes, such as, concentric circles, circles, lines and stars. Circular shapes were the most common accounting for 41.7% of the total abstract drawings and several of these had additional spikes, or some type of protuberance, on their surfaces, which are reminiscent of representations of the HIV virus. Small dots were also commonly represented (41.6%).

Harmful

Some drawings included items; for example, an ill person which indicates that children consider micro-organisms to be harmful, although only three children drew a 'harmful' micro-organism (Figure 5.25). Several comments indicate that micro-organisms are thought to be unpleasant or offensive, *'each ring is a different shade of green with millions of purple dots floating around on it (yuk!)'* (haj67); *'green, slimey, watery liquid (see through), blobs of goo'* (haj78).

Figure 5.25
Year 6: Cartoon-like drawings

haj8



sj53

Year 9

Table 5.15 shows the range of microbial drawings. Cell-type structures were represented in 83.3% of the drawings indicating that this age group considers micro-organisms as single-celled organisms, and of the few annotations, two children describe their drawings as, 'a *single celled micro-organism'* (ca3); *'single celled organism'* (ca5).

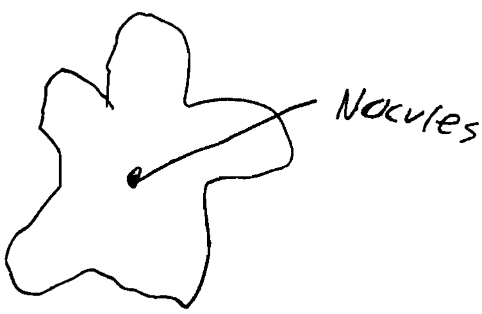
Table 5.15
Year 9: Morphology of drawings n=89

Appearance /morphology	Percentage
Amorphous	54.0
Bacterial Cell	16.9
Animal like	9.0
Anthropomorphic	10.1
Abstract	15.7
Other e.g. sperm, animal, plant cells	12.4

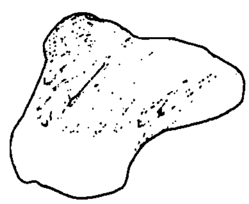
Total may be more than 100% due to multiple drawings

Amorphous cells accounted for just over half of the drawings and recognisable bacterial cell shapes were also drawn with the bacillus the most commonly represented (Figure 5.26). Other micro-organisms were under-represented, with only two children attempting an accurate drawing of a virus.

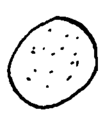
Figure 5.26
Year 9: Amorphous and bacterial cell drawings



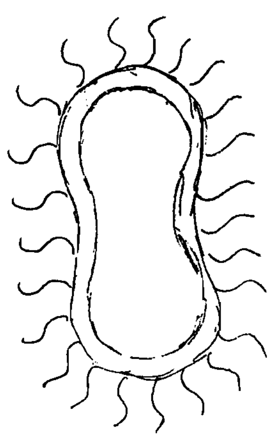
ca31



ca83



ca44



ca80

Some drawings of cells (12.4%) were more like a 'typical' plant or animal cell (Figures 5.8, 5.33); the drawings seem to signify that micro-organisms are single cells and previous knowledge is employed to depict micro-organisms, although this knowledge is often partial and confused in relation to micro-organisms:

ca18	*Aah, that's some kind of micro-organism and I can't remember what it was. I just know it from… um, sec, has a cell, I think it, yeah, it's got cell walls so it's probably a plant cell of some description. Oh! I know what it is. OK, no I don't. I just know, I just drew something very basic. Um.*
Interviewer	*So, this is a specific type of micro-organism?*

ca18	*Yeah, just from what I know of.*
Interviewer	*You've drawn a nucleus on both, what else do you think they'd look like on the inside?*
ca18	*They would also have a cytoplasm. And a membrane. Ah, also, plant cells would have ah, cell wall, vacuole and most would also have chloroplasts.*

A substantial minority of drawings (9.0%) indicated that some children in this age group consider micro-organisms to look like little animals (Table 5.16); invertebrate species were the most common (Figure 5.27) and all but one (9.0%) of the animal-like drawings were anthropomorphised in some way. A further 10.1% of the drawings were anthropomorphic representations (Figure 5.28).

Figure 5.27
Year 9: Types of animal-like drawings

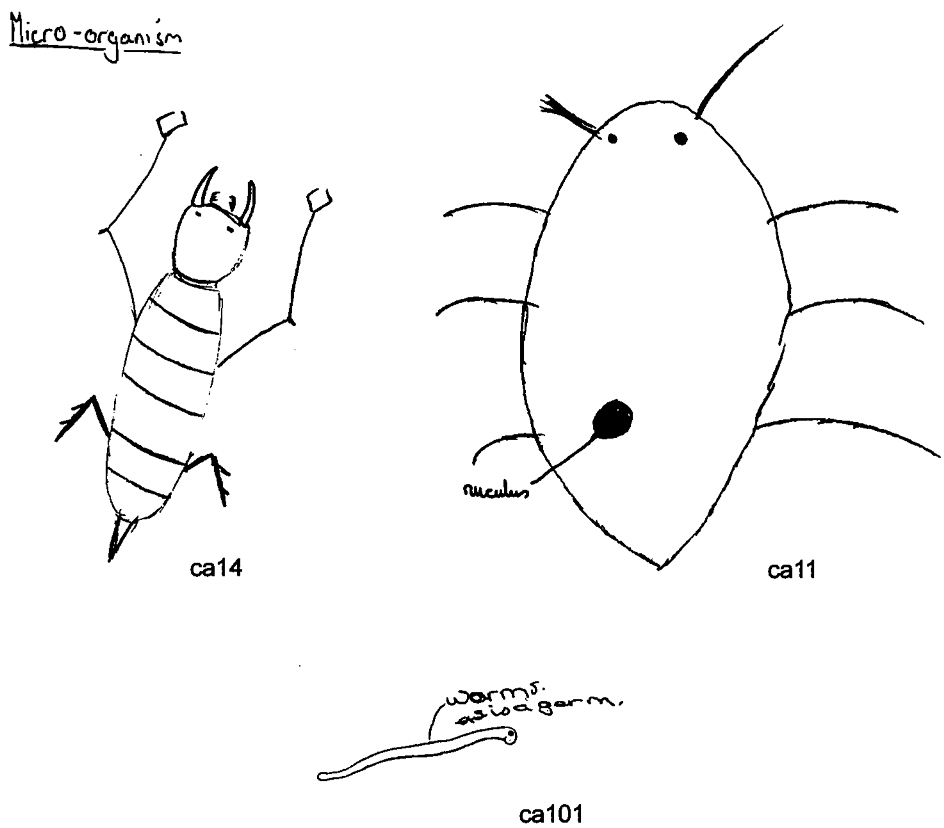
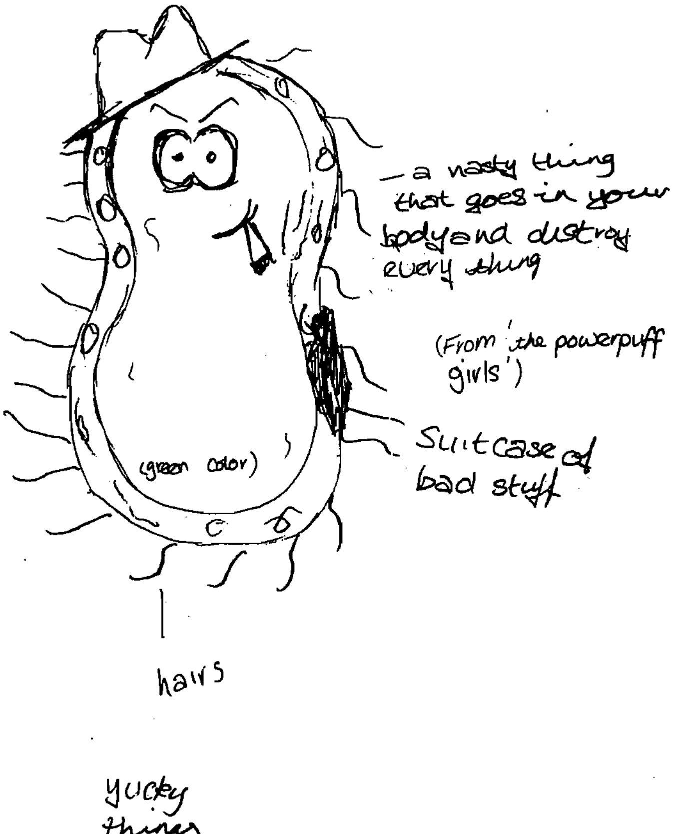


Table 5.16
Year 9: Types of animal-like drawings n=8

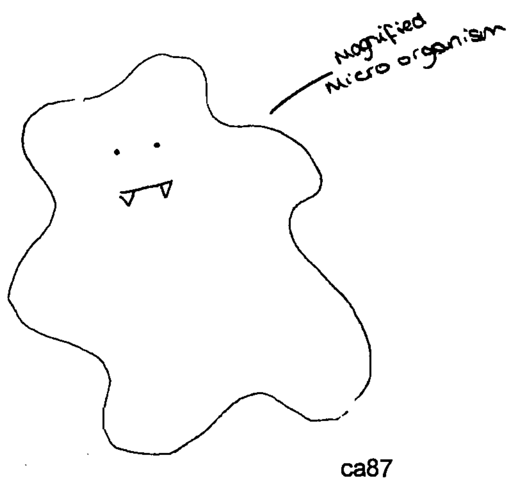
Types	Percentage
Insects	37.5
Tadpoles	0
Worms / caterpillars	50.0
Other e.g. Frog, cartoon	12.5
Anthropomorphised drawings	87.5

Total may be more than 100% due to multiple drawings

Figure 5.28
Year 9: Anthropomorphised drawings



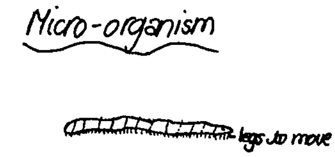
ca76



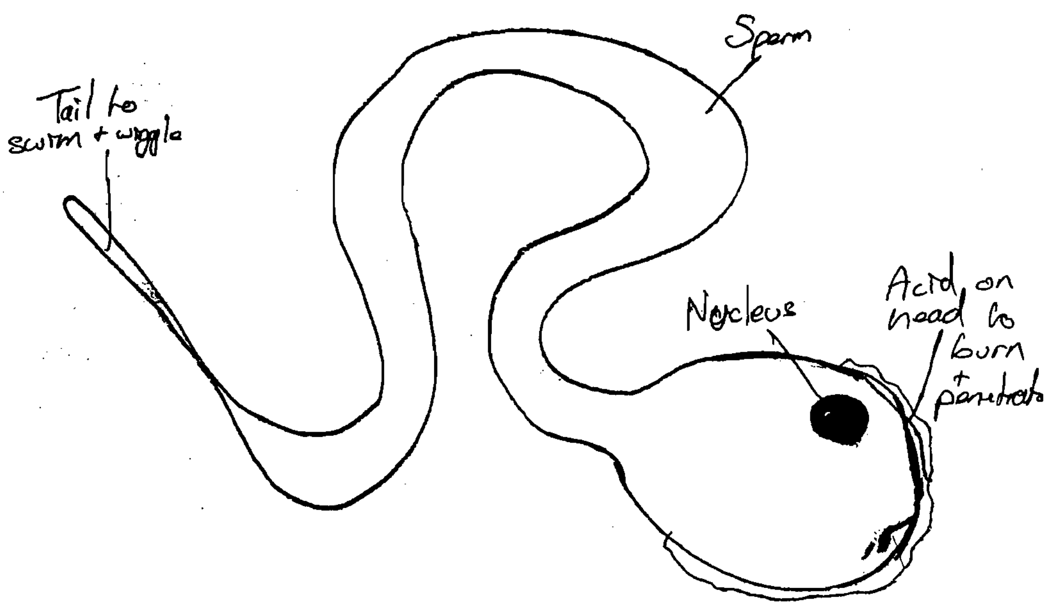
ca87 ca1

External features (Figure 5.29) were primarily drawn on animal-like and anthropomorphic drawings. Facial features and limbs account for the majority of the features drawn indicating an anthropocentric perspective, some explanations of their function were provided and indicate teleological thinking, *'tail to wiggle'* (ca39); *'little things to move'* (ca87). However, the majority of the drawings had no external features (73.0%) and only one child commented on colour.

Figure 5.29
Year 9: External features



ca85



ca24

Table 5.17
Year 9: External features of drawings n=89

External features	Percentage
Hairs	11.2
Tail	5.6
Facial features	18
Legs	7.9
Arms / hands / wings	1.1
Head	1.1
Spikes	1.1
Tentacles / antennae	6.7
Colour	1.1
None	73.0

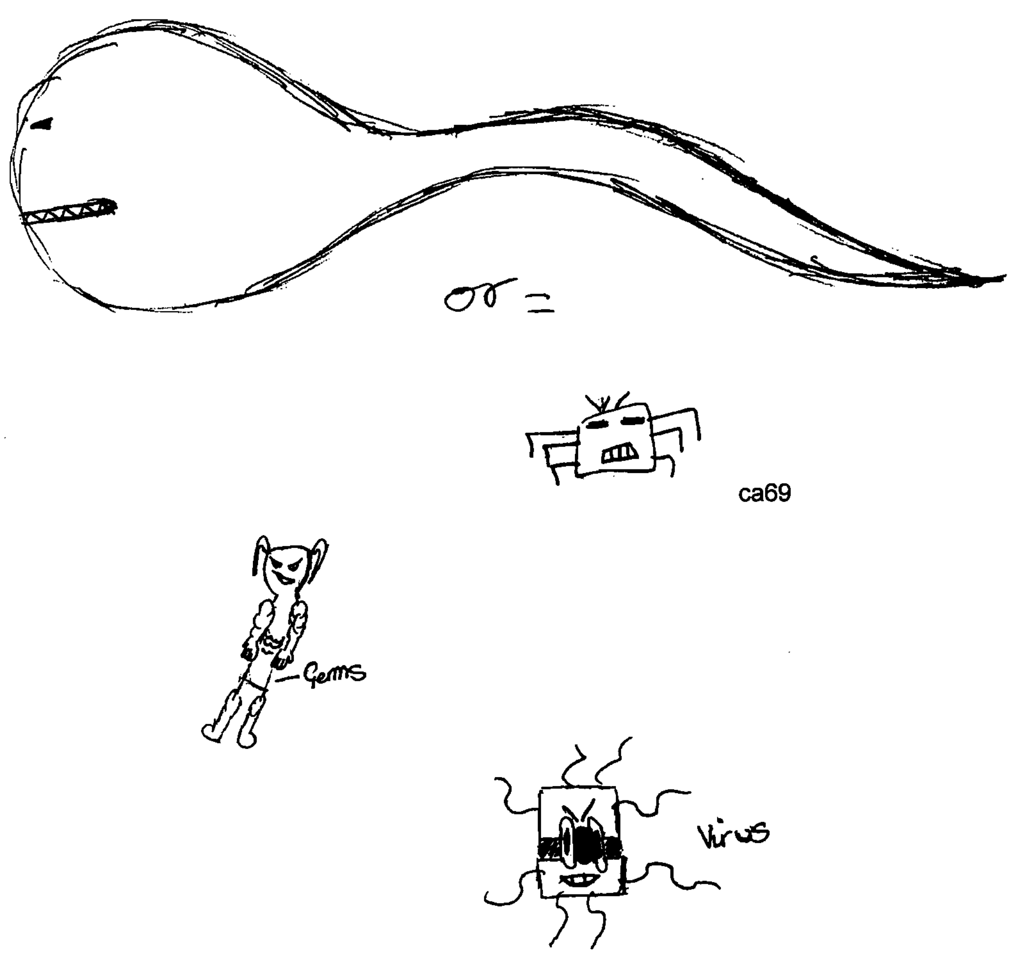
Total may be more than 100% due to multiple features on drawings

Abstract drawings accounted for 15.7% of the drawings. The majority show some type of geometric shape, such as, concentric circles, circles, lines and stars, or a mixture of these, although no particular shape was more common than another.

Harmful

Several (9) drawings indicated that micro-organisms were regarded as harmful, for example, cartoon pictures showing monster like creatures, often with sharp teeth (Figure 5.30) and some annotations, *'acid on head to burn and penetrate'* (ca24); *'a nasty thing that goes in your body and destroys everything, suitcase of bad stuff, yucky things'* (ca76), suggest that micro-organisms are particularly invasive especially to the human body. Children hold anthropocentric ideas about micro-organisms and appear to be influenced by television and other forms of media in the way they portray micro-organisms.

Figure 5.30
Year 9: Cartoon-like drawings



ca69

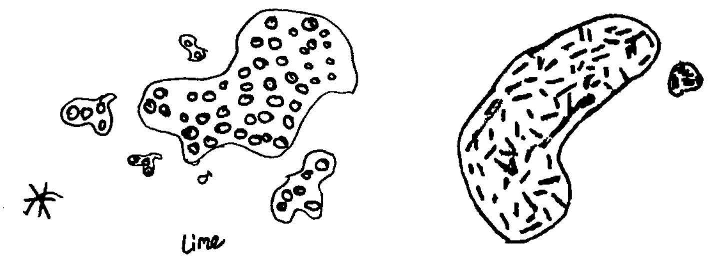
ca51

5.3.2 Internal structure

Year 2

The majority of drawings (77.4%) did not provide any internal detail, this is not surprising as most children drew a small animal, or human figure, and provided external detail. However, just over half (17) of those children that drew a cell-type structure did provide some internal detail, the majority drew small repeated dots to suggest some kind of internal substance and three children drew a single large mass (Figure 5.31).

Figure 5.31
Year 2: Drawings indicating internal structure



hai45 hai57

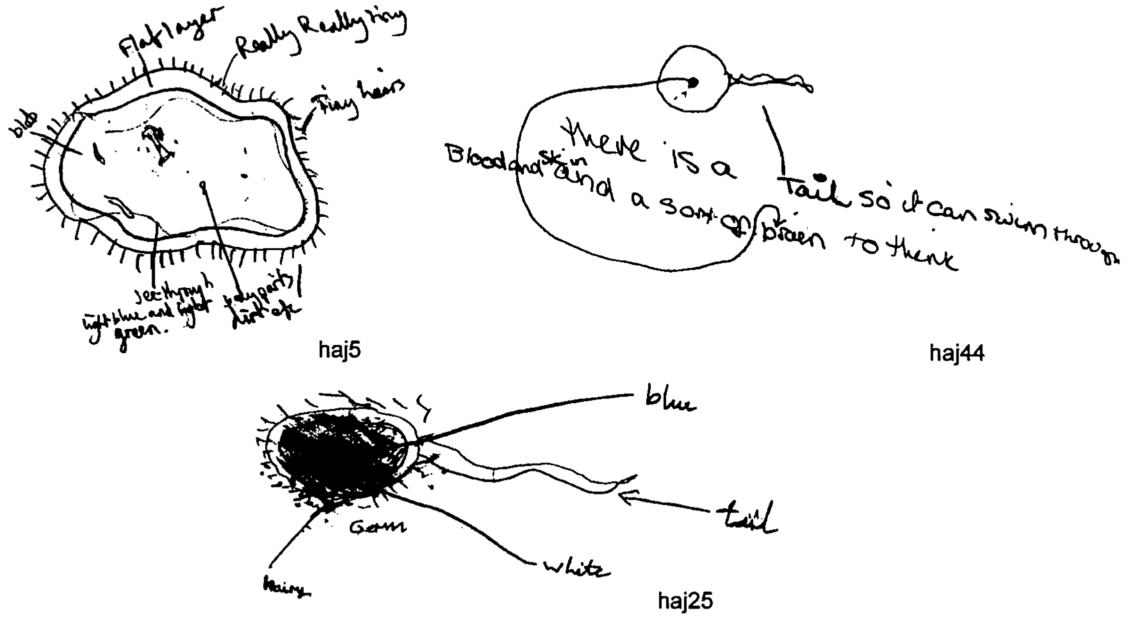
Annotations suggest that these children do not understand what is inside a microbial cell, *'little dots in the middle because they are stones?'* (hai34); *'the bits are inside it'* (hai64), but may have been influenced by seeing drawings and diagrams of cells, or innately know that micro-organisms cannot be hollow. This child's ideas offer an anthropocentric perspective about the internal structure of micro-organisms:

hai58	*Oh, um, it would be all black inside um, it would have a little brain, um, and, it would be squidgy. Um..*
Interviewer	*OK. And what would it's brain be for?*
hai58	*Well, just to think what bits to um, if it bites, what bits to bite and stuff.. And like, what bits not to bite, and things*

Year 6

Over half (56.0%) the drawings gave no indication of internal structure; some drawings appeared empty. However, 38.7% of the drawings gave an indication of internal mass. These drawings fell into two major groups, (Figure 5.32), one which indicated the micro-organism filled with an unnamed, unstructured substance represented by many tiny dots; although some annotations indicate that these are small micro-organisms inside a large one. The second type of drawing was characterised by a single large spot. Four children (2.4%) referred to this as the nucleus, with one child indicating anthropocentric ideas labelling it, *'a sort of brain to think'* (haj44). A few children also drew an outer layer. Some children clearly have a partial understanding of cell structure and that micro-organisms are 'cells', although they have attributed the features of typical eukaryotic cells to their drawing. These children have probably been influenced by drawings of 'typical' cells that they have studied or seen in reference books rather than any direct learning about microbial structure.

Figure 5.32
Year 6: Drawings indicating internal structure



A small number of children (9) seem to associate microbial, especially viral reproduction with internal structure; eggs, or smaller micro-organisms, were drawn inside a larger one. Five of the eleven interviewees indicated that smaller micro-organisms could be found inside a bigger one, although as the statements below indicate, the relationship between different micro-organisms is confused:

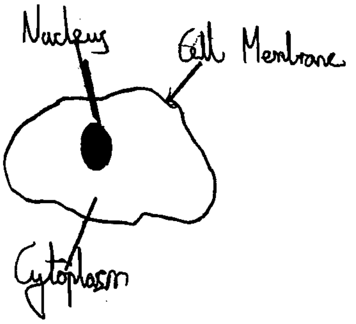
sm21	*sort of like little... like little small things like watery liquid, or something, inside.*
Interviewer	*Would they have anything else in the liquid?*
sm21	*Bacteria.*

Year 9

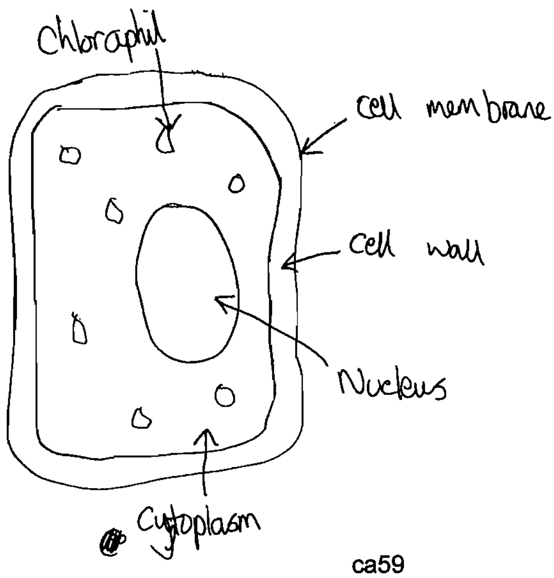
About three quarters of the drawings (75.3%) had examples of internal structure (Figure 5.33). Three features were noted, an inner mass often represented by many tiny dots, a single large dark spot and an outer layer; these were labelled cytoplasm, nucleus and cell wall, or cell membrane, respectively in 31.5% of the drawings. Internal structure is more closely related to typical eukaryotic cells rather than micro-organisms although these children do seem to understand that cell organelles have a function although their ideas indicate anthropocentric ideas and partial understanding:

ca54	*It's [referring to the nucleus] the ah, control centre for the cell. And then it literally tells, tells the cell what to do.*
Interviewer	*and what sort of things does it do?*
ca54	*Ah, in the case of a plant cell, it produces energy for the plant, like photosynthesis.*

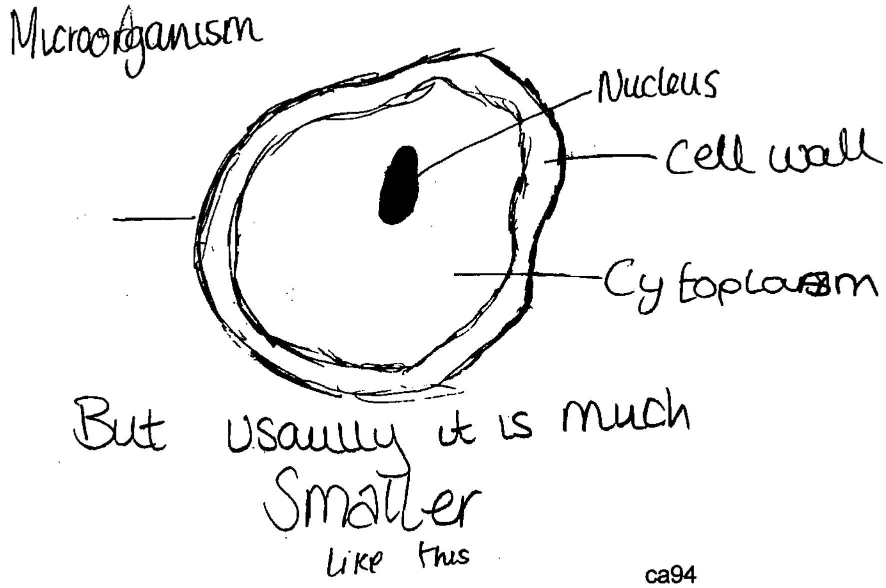
Figure 5.33
Year 9: Drawings indicating internal structure



ca10



ca59



ca94

The remainder of the drawings suggest that the micro-organisms have no internal structure, or content, or were focussed on external anthropomorphic characteristics. However anthropomorphic ideas and anthropocentric thinking about internal structure is evident:

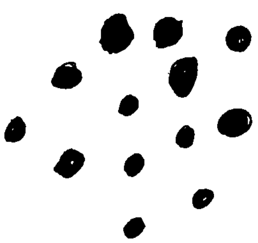
ca78	*Oooh, gooey and lots of ah, white stuff where the white blood cells, they ah…*
interviewer	*So would they have any structure inside them? Or would they just be this gooey stuff?*
ca78	*They, they wouldn't have. OK. They would have a backbone, I think. I think they'd probably have a backbone. And I think they have little eyes so they could see where they're going.*
Interviewer	*Why do they have a backbone?*
ca78	*Um, so they can bend.*
interviewer	*And why do they need to bend?*
ca78	*Um, so they can move around, and eat the, oh, they'd have teeth as well. Just little tiny ones.*
Interviewer	*And what would they be for?*
ca78	*Um, to eat the white blood cells.*

5.3.3 Single or repeated drawings

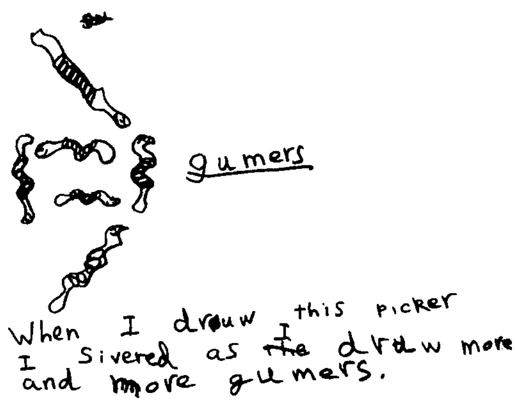
Year 2

Repeated drawings were found in just over a third of drawings (34.6%). Abstract and animal-like drawings were most commonly drawn as repeated examples rather than the drawings of cells. These drawings suggest that children think micro-organisms are rarely found singly but occur in large numbers (Figure 5.34).

Figure 5.34
Year 2: Repeated drawings



tb31



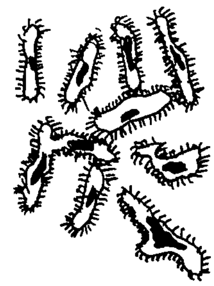
tb34

Year 6

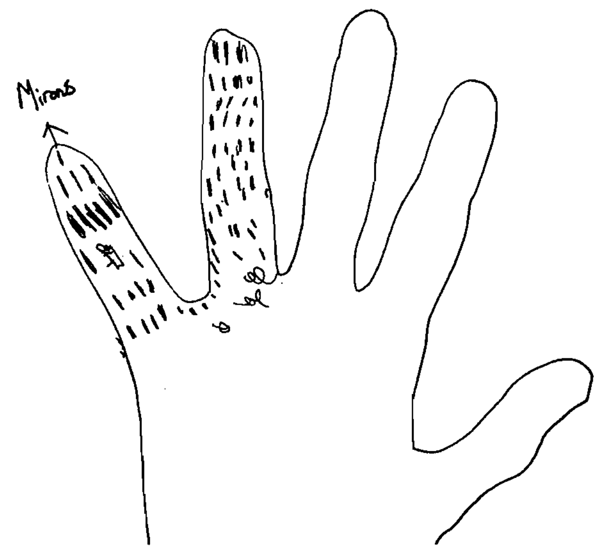
62 children (37.3%) drew repeated drawings of micro-organisms; the majority of these fell into the abstract category described earlier. Some of the repeated drawings could be a factor of the type of representation, for example many dots on the page; others were drawn in connection with another item (Figure 5.35). Children also drew repeated versions of 'cells' and those that drew animal-like or anthropomorphic pictures suggested the presence of many micro-organisms. It would seem that children have some understanding of microbial colonies and reproduction. The repetitive nature of the drawings seems to indicate that a micro-organism is thought to be a single entity rather than a complex multi-cellular organism.

Figure 5.35
Year 6: Repeated drawings

sm9



sj25

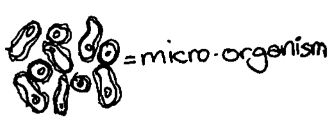


sj39

Year 9

Very few representations were of repeated drawings (10.1%) and the biggest group was of abstract drawings (Figure 5.36). This finding adds to the evidence that children consider micro-organisms to be single cells, although the notion of microbial colonies is not evident. The findings may, however, be an artefact of the instructions for the task, or that children are more used to drawing, or seeing in text books a single 'typical' cell.

Figure 5.36
Year 9: Repeated drawings



ca20

5.3.4 Summaries, progression and overview

A résumé of the findings about morphology, external appearance and internal structure of micro-organisms is presented below.

Year 2

- Over half the drawings were of animals;
- Invertebrates and humans were the most commonly drawn animals;
- Worms and insects are the most commonly drawn invertebrates;
- Abstract entities account for 30.2% of the drawings;
- Single cells were drawn by a substantial minority;
- Anthropomorphic and cartoon representations were common (49%);
- Facial features and legs were the most commonly drawn external features;
- Drawings indicate that micro-organisms are thought to be harmful;
- Internal structure is not understood;
- Single representations which were repeated indicate the notion of large populations;
- Anthropocentric ideas related to harmful nature of micro-organisms were connected with appearance and structure.

Year 6

- Over half of the drawings were of 'cells';
- Recognisable bacterial cells were drawn and a bacillus shape was the most commonly drawn;
- Animals represented about one third of the drawings;
- Invertebrates and humans were the most commonly drawn animals;
- Insects were the most commonly drawn invertebrates;
- A substantial minority of anthropomorphic and cartoon-like representations were drawn (18%);
- Hairs, facial features and legs were the most commonly drawn external features;
- Abstract entities account for a substantial minority of drawings;
- About one third of drawings show some internal structure;
- Single representations which were repeated indicate the notion of large populations;
- The majority of drawings do not indicate that micro-organisms are harmful but some are associated with unpleasant items e.g. slime.

Year 9

- The majority (83.3%) of drawings were of 'cells';
- Recognisable bacterial cells were drawn and a bacillus shape was the most commonly drawn;

- Drawings of cells were frequently based on typical eukaryotic cells;
- A substantial minority of drawings were of animals;
- Invertebrates, such as, worms and insects were the most commonly drawn animals;
- A substantial minority of anthropomorphic and cartoon-like representations were drawn (18%);
- Facial features and legs were the most commonly drawn external features;
- Internal structures were drawn and based upon eukaryotic cell organelles;
- Anthropocentric ideas related to harmful nature of micro-organisms were connected with appearance and structure.

Progression

Morphology and external features

A more scientific view of micro-organisms as single cells increases with age, although more Year 6 children drew a recognisable bacterial cell than Year 9 children. Figure 5.37 shows the trend in children's ideas indicating that progression does occur with respect to the morphology of micro-organisms. Fewer children in Year 9 consider micro-organisms to look like little animals compared to the younger age groups and anthropomorphic ideas also reduce with age. However, it is worth noting that anthropomorphic ideas are retained by a substantial minority of Year 9 children (Figure 5.38). The most commonly drawn external features were facial features and legs which indicates anthropocentric thinking in all age groups.

Figure 5.37
Year 2, 6 and 9: Drawings of microbial morphology

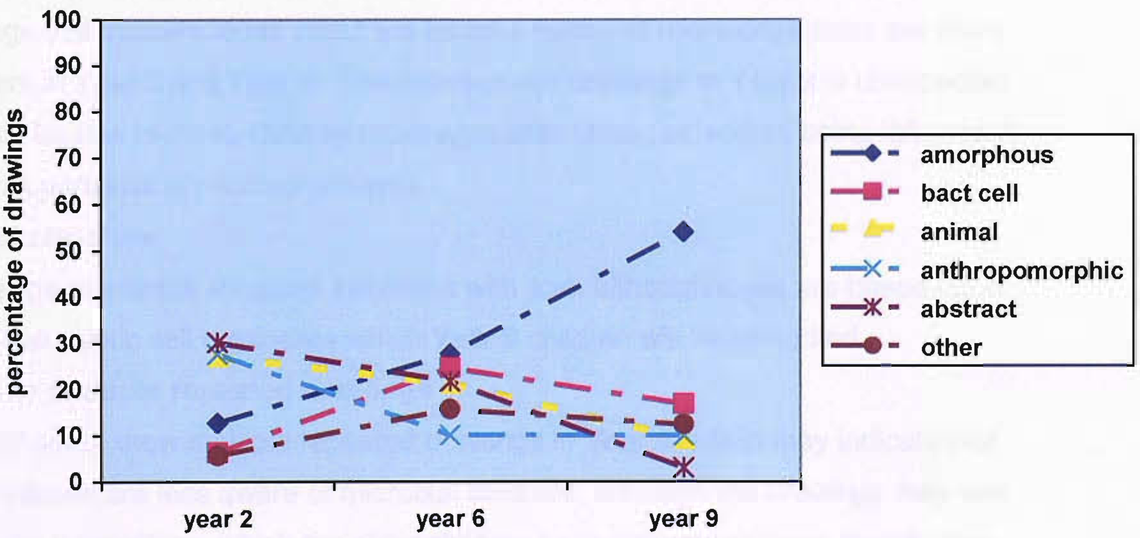


Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Abstract drawings decreased with age, which suggests that younger children are more uncertain about what micro-organisms look like compared to older children. Year 9 children also drew more familiar cells e.g. sperm cells in the 'other' category, whereas younger children drew complex fantasy drawings, indicating that older children know that micro-organisms are single cells, although all the drawings indicate an uncertainty about what micro-organisms really look like. Drawings in all age groups appear to be based upon what children are familiar with and what they have recently been taught; for example, many Year 2 children drew invertebrates, typical of the 'mini beasts' they will have encountered in lessons at school, whilst Year 9 children tended to draw cells which are reminiscent of typical plant or animal cells.

Figure 5.38
Year 2, 6 and 9: Anthropomorphised drawings

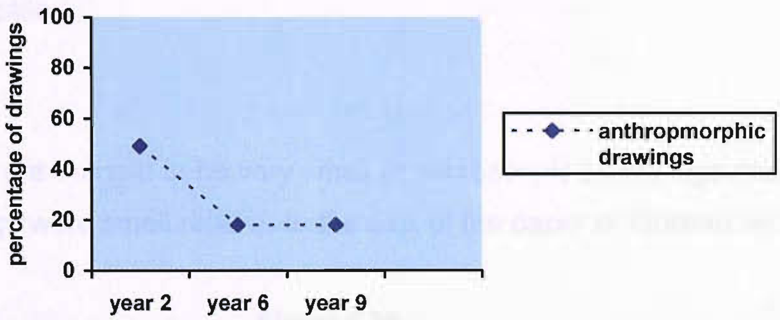


Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Harmful appearance

Drawings that indicate ideas about the harmful nature of micro-organisms are more prevalent in Year 2 and Year 9. The monster-like drawings in Year 9 is unexpected and may be due to these children retaining earlier ideas, as well as being influenced by media portrayal of micro-organisms.

Internal structure

Knowledge of internal structure increases with age, although ideas are based upon typical eukaryotic cell organelles which Year 9 children will have studied.

Single or multiple repeated drawings

Fewer children drew multiple repeated drawings in Year 9, which may indicate that these children are less aware of microbial colonies, although the drawings may well reflect the instructions, which the older children have interpreted more literally than the younger age groups.

Overview

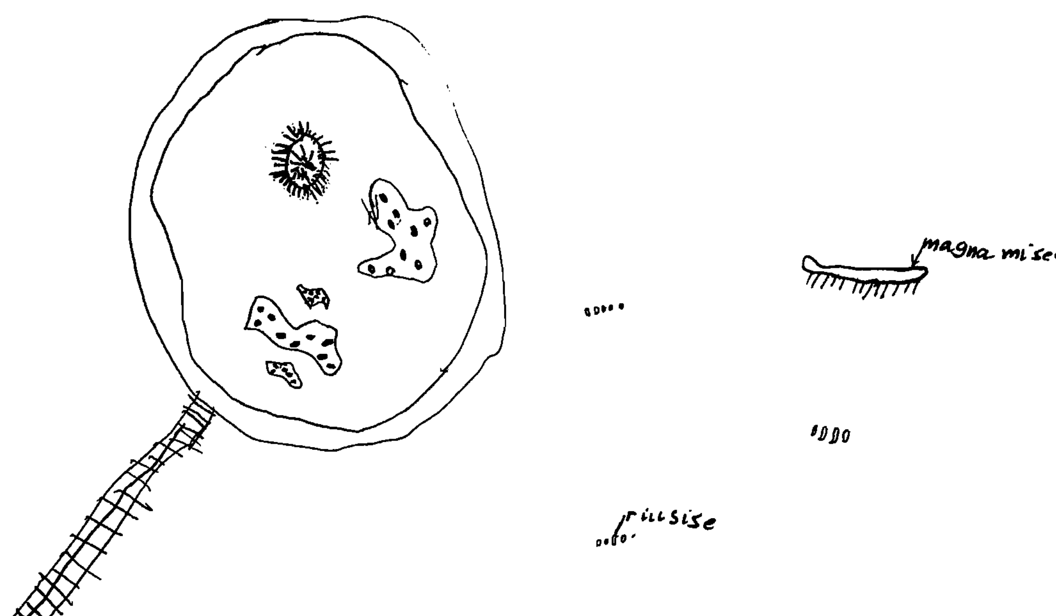
Understanding that micro-organisms are single cells increases with age, although the detailed morphology and structure of different micro-organism is not generally understood by any age group. Year 9 tend to refer to typical eukaryotic cell structures which they will have learnt about in school. Bacterial cells, especially the bacillus are the most commonly known microbial shape. Animal and anthropomorphic drawings were present in all age groups and facial features and legs were commonly drawn. The number of animal and anthropomorphic drawings decreased with age, their frequency levelled off at Year 6, which indicates that anthropocentric thinking is entrenched, at least for a small percentage of children. The findings indicate that the majority of children do not have a good understanding of the morphology of micro-organisms; drawings refer to things previously learned and alternative ideas to accepted scientifically accepted ideas are common.

5.4 Size and scale

Year 2

Micro-organisms are thought to be very small or microscopic by this age group, 40.2% of drawings were small relative to the size of the paper or labelled as tiny or small.

Figure 5.39
Year 2: Drawings to indicate size



hai20 tb16

Fourteen drawings indicated that magnification was required, *'I have drawn it big because it is small and you would not be able to see it if I had drawn it normal size'* (hai65), whilst two others did not draw anything at all because as they stated, *'you can't see germs'* (si45) and (si30). Three drawings showed some kind of magnifying apparatus (Figure 5.39). Sixteen children (11.5%) made a brainstorm comment about size and eleven suggested that germs could not be seen because they were small, *'one cannot see a germ because they are very, very, very, very, very, very small'* (si1). All the children who were interviewed considered micro-organisms to be too small to be seen without magnification, *'bacteria, you can't see, I don't think and viruses, I think you can see if you have a very good magnifying glass'* (si38).

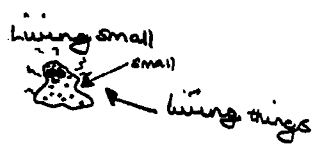
The comment above indicates that children of this age do not have an indication of the actual, or relative, size of micro-organisms. Children frequently referred to an object they considered to be small when attempting to clarify microbial size rather than providing any measurement; for example, *'I think germs are small dots'* (hai66); *'Umm, um some of them are a size as when you sharpen a pencil, really is the size of the end'* (hai61), or physically indicated the size using their thumb and forefinger squashed together, indicating that micro-organisms were smaller than the space between. Two children suggested that size was related to virulence in some way and one child refers to an everyday experience, *'Well I've seen fungus before...Well I was at my uncle's and I was about to make a sandwich cause my uncle sometimes is really busy and I make my own, myself a sandwich, and I got some bread down and I took it out of the package and I saw all this blue stuff all over it and so I got my uncle and he told me it was fungus'* (si38).

Year 6

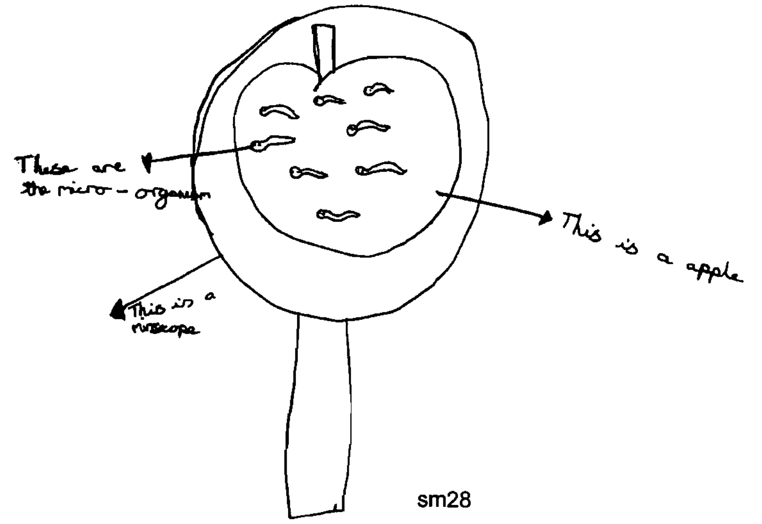
Children in this age group consider micro-organisms to be small, or microscopic, 62.0 % of drawings were small in relation to the paper, or were labelled with a term such as tiny, or very small. Some drawings included additional apparatus, or a comment (13.3%) indicating that they could not be seen unless they were magnified (Figure 5.40) and 43.9% provided brainstorm information stating that micro-organisms were small, or microscopic, and thirty-nine comments indicated that a microscope was required to be able to see them, *'they're tiny!'* (haj78); *'micro-organisms are so small you need a microscope to see them'* (sj33). All those interviewed considered micro-organisms to be too small to see without being magnified, *'Ah, not with my own eyes. Aided, with a microscope, but yeah'* (haj12).

Figure 5.40

Year 6: Drawings to indicate size



sm17



sm28

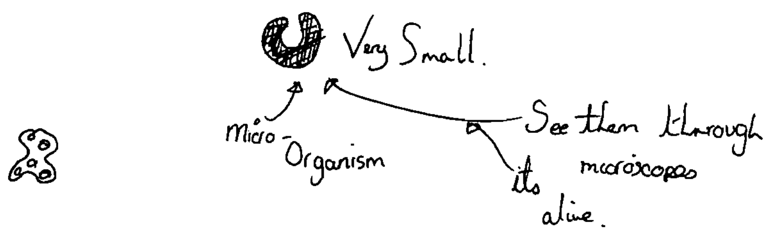
Very few children (3) offered any idea about actual size and those that did provide some idea were unrealistic in their estimates; for example, one drawing showed micro-organisms magnified by x5 and x10 and another drawing labelled the micro-organism as 0.3 mm. Comments also suggest difficulty in understanding how small micro-organisms are and children referred to small items in an attempt to explain the size, '*small things, like particles, the same size as a couple of grains of rice*' (sm38), '*well they'd be very small, so small that we couldn't even see them. Probably be smaller than a crumb. Crumb of bread*' (sm17). These findings would seem to indicate that whilst there is a good understanding the micro-organisms are small, and the term microscopic is used widely, there is little appreciation of what this actually means. Two interviewees used standard measures to indicate size and one had accurate ideas, for bacterial cells, '*I think, um, microbes can be like, a millionth of a metre and a thousandth of a millimetre, or something, microns*' (haj12).

Further exploration of size gave rise to suggestions that micro-organisms vary in size. Fungi were regarded by three interviewees as the biggest; fruiting bodies and fungal mycelia which children had seen were given as reasons, suggesting that first hand experience was important in developing their ideas even if this was at the macroscopic level, '*Yeah, I've seen fungus, seen like mushrooms... And I've seen like, virus because like, I had rashes and like, chicken pox is a virus and I've had that....... Um, viruses are quite big because they can spread*' (haj77). Viruses were also regarded as the largest by three others and reasoning was associated with disease and viral proliferation, as the statement above suggests.

Year 9

Children in this age group regard micro-organisms as very small, or microscopic, 53.9% of drawings were small relative to the size of the paper, or labelled to indicate that children consider them very small (Figure 5.41). Comments confirm this view, *'so small you can't even see it'* ca90, or that they needed to be magnified in order to see them, *'very small, see them through a microscope'* (ca74).

Figure 5.41
Year 9: Drawings to indicate size



ca93 ca74

About two thirds (66.7%) of this age group made a brainstorm comment about the microscopic size of micro-organisms, *'can't be seen without being magnified, a tiny living thing, micro means very small'* (ca89), and 44.9% indicated that they cannot be seen without magnification. All the children interviewed thought that micro-organisms were very small and that they required a microscope in order to see them, *'because they're too small to see, you have to have a microscope'* (ca100).

Ideas about actual size were not common, only one drawing indicated a scale and two interviewees attempted to use standard measures, *'smaller than in millimetres'* (ca94) and *'one millionth of a micron'* (ca18). It would seem that this age group does not have a clear understanding of the size of micro-organisms. The majority of those interviewed thought that different micro-organisms would be different sizes and viruses were considered to be the biggest by three children. Reasoning was based upon viruses as agents of disease and their proliferation, *'viruses are.........um cause viruses can easily spread.... with viruses, sort of like, you know, it's easy to catch it'* (ca23).

5.4.1 Summaries, progression and overview

A résumé of the findings about the size and scale of micro-organisms is presented below.

Year 2

- o Micro-organisms are thought to be small or microscopic;
- o Micro-organisms need to be magnified in order to see them;

- o Actual size is not understood and everyday objects are used as a comparison; standard measures used by two children;
- o Relative size of fungi, bacteria and viruses not known but virulence regarded as a reason for being bigger.

Year 6

- o Micro-organisms are thought to be small or microscopic;
- o Micro-organisms require a microscope to be able to see them;
- o Little understanding of actual size; small items used to attempt to indicate size; standard measures used by five children;
- o Relative size of fungi, bacteria and viruses is confused, viral size associated with virulence and fungal size with macroscopic structures.

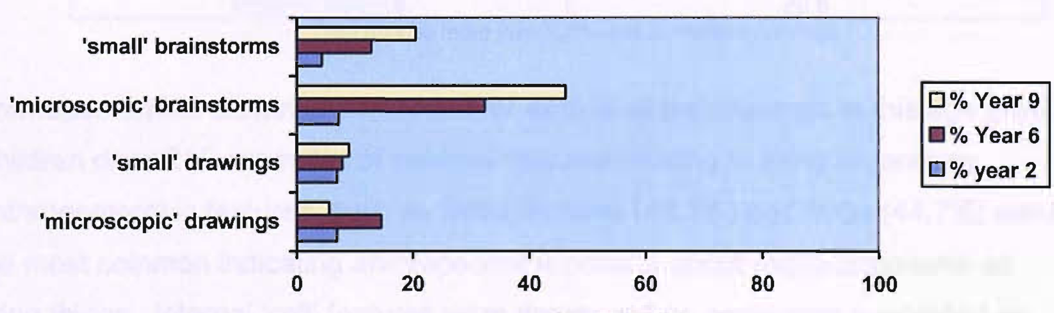
Year 9

- o Micro-organisms are thought to be small or microscopic;
- o Micro-organisms require a microscope to be able to see them;
- o Little understanding of actual size; terms such as 'tiny' used to indicate size; standard measures used by two children;
- o Relative size of fungi, bacteria and viruses unknown and viral size is related to related to virulence.

Progression

There seems to be little difference in the ideas that the different age groups have about the size of micro-organisms. Reference to size in drawings and brainstorms largely increased with age (Figure 5.42) and the term 'microscopic' was used more frequently as children got older, although what it actually means is not generally understood. Standard measures to provide an indication of the size of micro-organisms were not used by Year 2 and infrequently by older children.

Figure 5.42
Year 2, 6 and 9: Terms used to indicate size



Overview

Children in all age groups have an innate sense that micro-organisms are small and cannot be seen without magnification. Understanding what microscopic means is not generally understood by any of the age groups and reference to familiar small objects to make a comparison is used by Year 2 and Year 6, whilst older children simply use descriptive terms such as tiny or microscopic. Everyday experiences, for example, having a viral infection or seeing fungal fruiting bodies are used as reference points to compare the size of micro-organisms. The notion of virulence was used as a measure of size in all age groups

5.5 The living and non-living state

5.5.1 Indication of living

Year 2

Micro-organisms are considered to be living by the majority of Year 2 children (Table 5.18), 73.8% of drawings indicated an association with living things and all but one of the children interviewed asserted that micro-organisms are alive. However, contradictory ideas were noted, as this anthropocentric response suggests:

hai50	*Um, well, it crawls all over us and um, and it kept spitting at us, all over our body*
Interviewer	*Do you think, they're living things?*
hai50	*Um... no.*
Interviewer	*Why do you think, they aren't alive?*
hai50	*Well, 'cause otherwise they would probably talk to each other but, never heard of a talking germ.*

Table 5.18
Year 2: Indication of living from drawings n=159

	percentage
External appearance / morphology	73.8
External features	135.2
Internal features	20.8

Total may be more than 100% due to multiple drawings

Anthropomorphic drawings accounted for 49% of all the drawings in this age group. Children drew 215 examples of external features relating to living organisms; anthropomorphic features, such as facial features (49.1%) and limbs (44.7%) were the most common indicating anthropocentric notions about micro-organisms as living things. Internal 'cell' features were drawn, but no comments suggested an association with cell structure; for example, one child labelled her drawing, *'tummy'* hai80, and another indicated that germs might be hosts for other organisms, *'there might be bugs in the germs'* (hai36).

A few children annotated their drawings, or made a brainstorm comment (Table 5.19). Many of the life processes were mentioned in association with micro-organisms, with reproduction and movement the most commonly referred to characteristics, *'germs need to travel on animals or insects. They can travel on their own but it takes them a long time because some of them don't have legs. Those that do have small ones so they're slow. The others slide along'* (ha1). Reproduction was associated with the idea of proliferation, 'a *germ is a tiny little thing and has lots of legs and lays eggs'* (hai59), often to other places or people, *'they can spread about onto other people'* (si17), and one comment suggested that micro-organisms cause harm, *'sucks blood, spreads lots'* (tb16).

Table 5.19
Year 2: Comments about living from drawings and brainstorms (n=159 drawings, n=139 brainstorms)

Comment	Percentage of drawings	Percentage of brainstorms
Living	0.6	10.8
Movement	3.8	1.4
Nutrition	1.9	1.4
Sensitivity	1.3	0
Reproduction	0.6	5.0
Growth	0.6	0
Structure	0	0

Year 6

Children in this age group consider micro-organisms to be living, 86.7% of drawings showed some association with living organisms (Table 5.20). Over half the children (57.9%) also provided information in their brainstorms relating to the notion of living and all of those children interviewed considered micro-organisms to be alive.

Table 5.20
Year 6: Indication of living from drawings n=166

	percentage
External appearance / morphology	86.7
External features	100.6
Internal features	38.7

Total may be more than 100% due to multiple drawings

Drawings provided 167 examples of external features related to living organisms, 'hairs' (35.5%) were the most commonly represented feature and many amorphous drawings showed structures which suggest cilia or flagella for movement. Anthropomorphic characteristics were represented on 18% of all drawings; facial features (18.7%) and limbs (21.1%) were the most frequently drawn, indicating an anthropocentric perspective about the concept of living. Four drawings (2.4%) had internal 'cell' features labelled, for example, *'DNA'* (haj76); *'nucleus'* (sj20), indicating an association with living things. A variety of the characteristics of living organisms related to the 'seven processes of life' were drawn and cited by children as evidence that micro-organisms were living. Movement and reproduction were the most commonly identified (Table 5.21). Structures to help micro-organisms move freely were commonly mentioned, *'legs that vibrate'* (haj6); '*yeh I think some kinds of bacterium have little feelers that can pull themselves along*' (haj12).

Table 5.21
Year 6: Comments about living from drawings and brainstorms
(n=166 drawings, n=164 brainstorms)

Comment	Percentage of drawings	Percentage of brainstorms
Living	4.8	25.6
Movement	12.6	3.7
Nutrition	0.6	3.7
Sensitivity	4.8	0.6
Reproduction	5.4	23.8
Growth	0.6	0.6
Structure (cell structure, organelles)	2.4	0.6

The idea that micro-organisms multiply quickly was common; *'they breed very fast'* (sj20); *'it breeds at an amazing rate'* (haj19). Drawings and annotations also indicated that micro-organisms reproduce quickly. The notion of the speed of reproduction often seemed to be connected to ideas about the pervasive and dangerous nature of micro-organisms, indicating teleological reasoning:

sj53	*Well um, for producing young, well, offspring, they multiply 'cause they can, a disease starts off not very, a cold, well, a disease can start off sort of very insignificant but then it gets worse and worse.*
Interviewer	*How come it gets worse and worse?*
sj53	*Because um they split in half and there is just more of them.*

Year 9

Year 9 children consider micro-organisms to be living. Drawings provided ninety-one examples (102.2%) of indications of being alive (Table 5.22). and 70.6% provided brainstorm comments about micro-organisms as living things. All those interviewed consider micro-organisms to be living.

Table 5.22

Year 9: Indication of living from drawings n=89

	percentage
External appearance / morphology	102.4
External features	52.7
Internal features	75.3

Total may be more than 100% due to multiple drawings

External features of drawings focussed on facial features (18%), limbs (9%) and hairs (11.2%) suggesting that some children in this age group have anthropocentric ideas about micro-organisms. Anthropomorphic drawings accounted for 18% of drawings. Drawings included a large number of labelled internal features (75.3%)

related to ‘typical’ cell structure; for example, *‘nucleus, cell membrane, cytoplasm’* (ca10); *‘cell membrane, cytoplasm, nucleus, chloroplasts’* (ca100), indicating an association with cells and their metabolic processes.

The most common comments on drawings and in brainstorms relating to the notion of living were about cell structure, although statements about their function were not made (Table 5.23). Other ideas relating to the seven life processes were less common, although movement, *‘tail to swim and wiggle’* (ca24); *‘legs to move’* (ca85) and reproduction, *‘millions of them’* (ca64); ‘use *the human body to reproduce, cells’* (ca18), were represented more frequently than any others.

Table 5.23
Year 9: Comments about living from drawings and brainstorms
(n=89 drawings, n=78 brainstorms)

Comment	Percentage of drawings	Percentage of brainstorms
Living	3.4	38.5
Movement	7.9	2.6
Nutrition	1.1	1.3
Sensitivity	0	0
Reproduction	0	3.8
Growth	0	1.3
Structure (cell structure, organelles)	31.5	23.1

Interviews revealed that children know that micro-organisms are single cells with particular organelles which enable them to survive, but they readily reverted to citing one or more of the seven processes of life as reasons for micro-organisms being alive:

Interviewer	*What does the nucleus do?*
ca54	*It’s the ah, control centre for the cell. And then it literally tells, tells the cell what to do.*
Interviewer	*Do you think they’re all alive?*
ca54	*Mm, yeah.*
Interviewer	*And what tells you that they’re living?*
ca54	*Um, they follow certain criteria for living things. Such as reproduction, um, excretion, things like that.*
Interviewer	*Anything else?*
ca54	*Um, I think they, they respire, I think.*

Children, at this age, seem to associate micro-organisms with aspects of living cells, but were uncertain about how to refer to these as evidence of living and preferred to use older, more stable knowledge, such as the seven processes of life stated in section 2.5 in Chapter 2.

5.5.2 Anthropocentric ideas

Year 2

Children in this age group have highly anthropocentric ideas about micro-organisms and their characteristics as living things; for example, reproduction (Figure 5.17) and movement, *'he crawls with his back facing the ground, it has 18 legs'* (hai5), while this child considers micro-organisms to be conscious beings:

hai61	*Um, because um, if they were not alive, they wouldn't really be able to get inside your body and they wouldn't be able to think of how you get inside your body.*
Interviewer	*So have they got a brain, to think?*
hai 61	*Um, they haven't really got a brain but it um, it's something that, they've got sort of a rememberence and they get um, they originally get told of how you get um, the different kinds, they get told how you get from one place to the other. That you want, that that bug wants to destroy the place that it destroys.*
Interviewer	*So, how do they get told?*
hai61	*Um, I think um, that a Mummy sort of reduces it into them.*

Association with humans, *'they live on our teeth'* (tb21); *'germs live in your tummy'* (hai77), in particular, causing harm or illness, are also offered as reasons for thinking that micro-organisms are alive, *'cause if they weren't alive they wouldn't be able to move to kill people'* (si48).

Year 6

Anthropocentric ideas about micro-organisms as living things were present in drawings (18%) and some comments suggest micro-organisms have free will to go where they please, *'there is a tail so it can swim through blood and skin and a sort of brain to think'* (ha44); *'it can walk and see where it's going'* (haj32). Other comments suggest that micro-organisms have emotions, *'micro-organisms don't like living in really cold and really hot places'* (sj32); *'they hate over 100° C and 0° C, they love body heat, they like sweet things'* (sj52), or that micro-organisms are alive because they cause harm to humans, again, indicating anthropocentric thinking.

Year 9

Anthropocentric comments relating to micro-organisms as living things were not common, although the following child indicates anthropocentric thinking together with an anthropomorphic view of microbial structure:

ca78	*They would have a backbone, I think. I think they'd probably have a backbone. And I think they have little eyes so they could see where they're going.*
Interviewer	*Why do they have a backbone?*
ca78	*Um, so they can bend.*
Interviewer	*And why do they need to bend?*

ca78	*Um, so they can move around, and eat the, oh, they'd have teeth as well. Just little tiny ones.*
Interviewer	*And what would they be for?*
ca78	*Um, to eat the white blood cells.*

Three of the children interviewed associated micro-organisms with humans and indicated that causing harm, or illness, was a reason for being alive:

Interviewer	*Are they all alive, all of them?*
ca78	*Um, yeah, I think so.*
Interviewer	*And what sort of things do they do?*
ca78	*Um, they um, feed off the white blood cells and then they take them away. And um, um, what did you say again? Sorry.*
Interviewer	*What sort of things do they do to tell you that they're alive?*
ca78	*Um, they're all kind of, make you really ill. And... yeah, I think that's it.*

5.5.3 Summaries, progression and overview

A résumé of the findings about living and non-living in relation to micro-organisms is presented below.

Year 2

- Micro-organisms are considered to be living;
- Reproduction and movement were the most commonly cited reasons;
- Harm caused to humans is given as a reason for living;
- 49% anthropomorphised their drawings;
- Anthropocentric ideas are common.

Year 6

- Micro-organisms are considered to be living;
- Movement and reproduction were the most commonly cited reasons;
- Reproduction in relation to harm caused to humans was cited as a reason for micro-organisms being alive;
- 18% anthropomorphised their drawings;
- Anthropocentric ideas were common, for example, suggesting micro-organisms have emotions and free will..

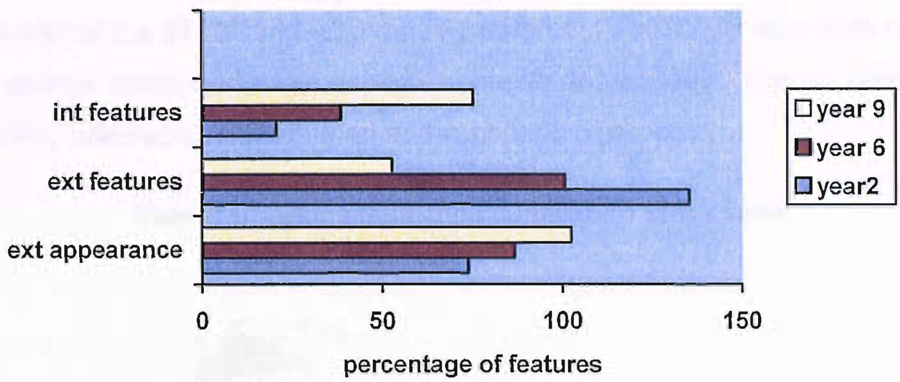
Year 9

- Micro-organisms are considered to be living;
- Cell structures were the key indicators in drawings;
- Life processes were also referred to, with movement and reproduction referred to most frequently;
- Harm caused to humans is given as a reason for living;
- 18% anthropomorphised their drawings;
- Anthropocentric ideas are uncommon.

Progression

Figure 5.43 shows that external appearance and internal features associated with living things increases with age and external features especially anthropomorphic features decrease with age. Characteristics of living change with age; overall seven processes are identified. Movement and reproduction are especially cited by Year 2 and Year 6, but Year 6 cites a wider range of living processes. The range and complexity of life processes associated with micro-organisms is progressively greater in diagrammatic representations as children get older whilst external features associated with the seven life processes reduces. Cell organelles appear more frequently in drawings of Year 9, although reversion to the more simple concepts referenced by younger children occurred when this age group talked about micro-organisms during interviews.

Figure 5.43
Year 2, 6 and 9: Features of 'living' from drawings



Anthropomorphic drawings reduce with age but stabilise between Year 6 and Year 9, although anthropocentric thinking reduces with age.

Overview

Progression of understanding about micro-organisms as living things increases with age; more complex ideas about what it means to be alive are more frequent in drawings of older children. However, their reasoning reverted to older, more stable knowledge, such as reproduction, respiration or excretion as some of the seven processes of life when discussing micro-organisms during interviews. Anthropomorphic ideas and anthropocentric thinking reduces with age, although some children in all age groups considered that causing harm to humans was a reason for micro-organisms being alive indicating a negative opinion about micro-organisms.

5.6 Disease, health and infection control

This section considers children's ideas about micro-organisms in relation to disease, prevention, cure and recovery, including issues relating to health, infection control and immunity. Aspects of the technological use of micro-organisms in disease prevention are presented under technological applications.

5.6.1 Micro-organisms and disease

Year 2

Connections between micro-organisms and disease are strong; *'germs are things that can get inside you and you get ill and poorly'* (hai72); *'germs can give you diseases'* (tb19), are typical comments. Drawings (Figure 5.44) also indicate that children think micro-organisms cause illness. A link was made by 74.5% with the photograph of the sick child; 65.5% made a comment on their brainstorms and over half (54.8%) of the 31 children who made a comment about microbial activity on their drawings mentioned some aspects of health and disease. Human illnesses were solely referred to indicating an anthropocentric perspective.

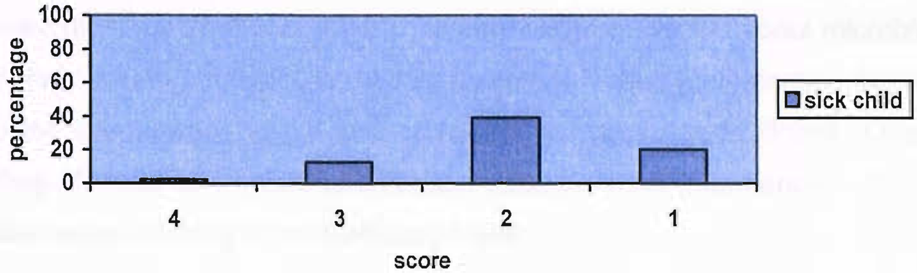
Figure 5.44
Year 2: Drawings indicating connection with illness

si41

- **The role of micro-organisms in disease**

Data from concept maps about the role of micro-organisms in connection with disease indicate different levels of understanding (Figure 5.45).

Figure 5.45
Year 2: Responses to photograph of sick child



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement – see Table 4.6)

Disease is the result of microbial activity (score 4)

Very few children (2.3%) indicated that microbial activity causes disease, *'he's sick, the germs aren't doing very well to him, 'some germs can be nasty'* (hai21); *this is a germ because he has red spots all over him because he has germs'* (hai43), and their comments suggest that symptoms are a result of microbial activity only, rather than an immune response to infection.

Cause of disease (score 3)

Relatively few children (12.7 %) connected micro-organisms, as the causal agent of disease, to the photograph of the sick child and their comments, *'because germs make you sick and this baby is sick'* (si9), indicate that micro-organisms are thought to cause disease directly rather than any effect they have on the body.

Microbial presence related to disease (score 2)

The majority of comments about the sick child (39.3%) indicate microbial presence was connected to the sick child, *'the baby has germs on his body'* (tb45); *'it looks like its got germs'* (hai45). The presence of micro-organisms seems to be sufficient to make the child ill and illness occurs instantaneously.

Sickness and micro-organisms are connected (score1)

One fifth (20.2%) of children offered alternative statements, which indicate that they are aware of some association between micro-organisms and disease, *'the little orange spots have something to do with germs'* (si31), and several comments indicate that disease and micro-organisms are the same thing, *'I think sick is germs'* (hai3); *'I think the spots are germs'* (hai68).

Year 6

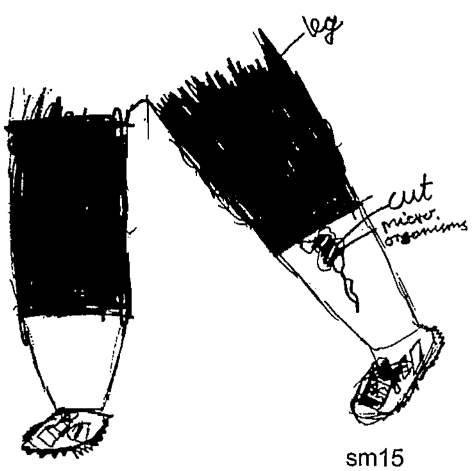
Year 6 children know that micro-organisms cause disease; *'lots are harmful and cause illnesses'* (sj17); *'micro-organisms can make you sick'* (sm5), are typical statements, and drawings (Figure 5.46) indicate that children understand the connection between micro-organisms and illness.

The photograph of the sick child was chosen by almost the entire cohort (95.2%) and 69.2% made a connecting statement to micro-organisms. Connections with disease were made by 26.2 % of the 38 children who commented about microbial activity on their drawing and 62.2% made a comment in their brainstorms. Six of those children interviewed thought that micro-organisms caused all illness. Others had a variety of ideas which were often based upon personal experience and indicate alternative thinking or contradictory ideas:

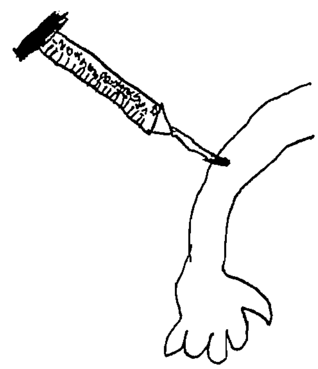
Interviewer	*Do you think all these, all diseases come from micro-organisms?*
haj77	*No, not all.*
Interviewer	*Have you any idea which ones don't?*
haj77	*Um, like from sheeps, like um, that foot thing……. Foot and mouth. That wasn't kind of like caused by germs or anything.*
Interviewer	*Do you know how that came about?*
haj77	*No, I think it, I think it got all the animals with the cloved hooves. They kind of like caught, like stuff in their hooves. And like, every time you like, went on holiday, you had to stand in those um, um, mat things with all the antibodies, like wash stuff.*

Data reveals anthropocentric thinking about microbial infection; children did not refer to other animals or plants becoming ill due to micro-organisms.

Figure 5.46
Year 6: Drawings indicating connection with illness



sm15

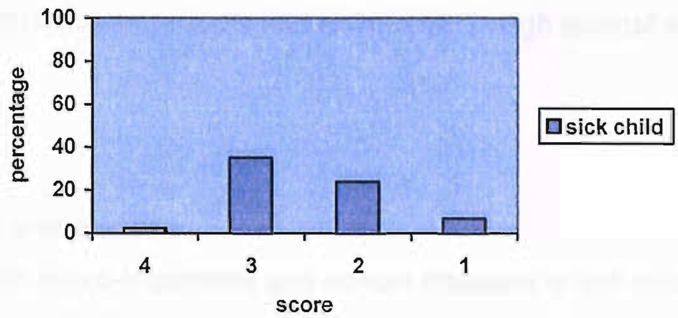


haj2

- **The role of micro-organisms in disease**

The overall pattern of responses to the photograph of the sick child can be seen in Figure 5.47. The most common response indicates that 35.5% of this group of children consider micro-organisms to be the causal agent of disease.

Figure 5.47
Year 6: Responses to photograph of sick child



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement- see Table 4.6)

Disease is the result of microbial activity (score 4)

Only four children (2.4%) provided sophisticated ideas, suggesting that the child was ill because of the effect of microbial activity although their statements, *'the outcome of germs'* (sm6); *'micro-organisms have done something to make the child ill'* (sm37), indicate their ideas are relatively simple and imprecise and do not express any ideas about immune response.

Cause of disease (score 3)

The most common response that micro-organisms cause the child to be ill was made by 35.5% of this age group. The majority of responses did not offer further detail about the aetiology of microbial disease, rather that micro-organisms are the active agent in causing illness. A small number of children (3) thought that the micro-organisms had multiplied and large numbers were necessary to cause the illness. For example; *'there are many bad micro-organisms in the child causing it to be sick'* (sm25) and, that the micro-organisms had to be distributed throughout the body, *'germs and microbes have spread around his body and made him ill'* (sj44).

Microbial presence related to disease (score 2)

Other responses (24.3%) indicate that the presence of micro-organisms is associated with illness. It would seem that illness is regarded by these children as a result of somehow simply coming into contact with micro-organisms. Five children provided statements about the child being infected with micro-organisms, *'I think this child has eaten bad micro-organisms'* (haj69); *'microbes infect his skin'* (sj17), which suggests that these children have some ideas about modes of infection, although it is the mere presence of micro-organisms that make the child ill.

Sickness and micro-organisms are connected (score1)

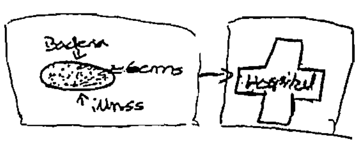
A small number of children (7.1%) made alternative statements which indicate a connection between micro-organisms and sickness although several were tautological.

Year 9

Micro-organisms and disease

The association with micro-organisms and human diseases is well recognised by this age group (Figure 5.49). Although only four children provided additional information on their drawings (Figure 5.48) about microbial activity, all of them indicated a connection with disease; 42.3 % of children made a brainstorm comment connecting micro-organisms to disease, *'infection, they can cause flu cold etc, mouldy bread, a nasty thing that goes into your body and destroys everything'* (ca76), and many listed a variety of illnesses, which included microbial and non-microbial diseases.

Figure 5.48
Year 9: Drawings indicating connection with illness

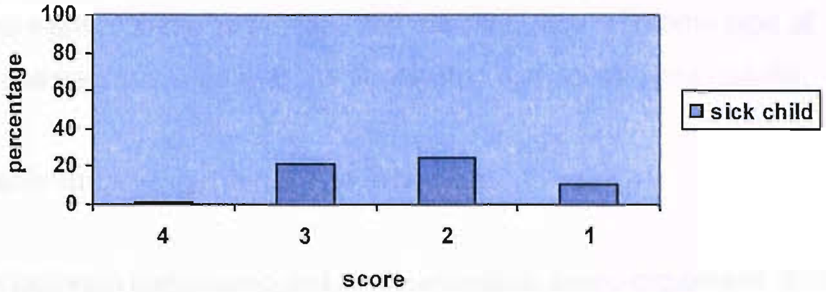


ca63

The photograph of the sick child linking it to micro-organisms was chosen by 57.3% of the age group. Interviews revealed that the majority of children (8/9) in this age group did not consider micro-organisms to be responsible for all disease, although only two children suggested alternative ideas; hereditary disease was given as the example by both. One child indicated confused and fragmented knowledge about the HIV virus:

Interviewer	*Um, do you think all illnesses come from micro-organisms?*
ca78	*Um, no. No.*
Interviewer	*What sort of other things don't?*
ca78	*Um, AIDS and um, um…*
Interviewer	*How do you get AIDS then?*
ca78	*Well, it's sexually transmitted disease.*

Figure 5.49
Year 9: Responses to photograph of sick child



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement- see Table 4.6)

Children have an anthropocentric perspective about illness as all comments were exclusively focussed on humans.

- **The role of micro-organisms in disease**

The overall pattern of responses to the photograph of the sick child can be seen in figure 5.49. Just over one fifth (21.4%) of children consider that micro-organisms are the causal agent of disease although slightly more (24.3%) indicate that micro-organisms are associated with disease.

Disease is the result of microbial activity (score 4)

Only one child commented that the child was ill because of microbial activity, *'germs have got into his body and affected his skin'* (ca35), although ideas about immune responses as a result of infection are not offered.

Cause of disease (score 3)

Just over one fifth (21.4%) suggest that micro-organisms are the active agent and have caused the child to be ill. Comments like, *'germs cause disease'* (ca38); *'germs make child ill'* (ca58), indicate that little else is known about the aetiology of disease, although one comment does suggest that micro-organisms invade the body, *'the micro-orgs get into the blood and make the child sick'* (ca12).

Microbial presence related to disease (score 2)

Just under a quarter of responses (24.3%) indicate that the presence of micro-organisms is associated with illness and 12 children (11.7%) indicate that the child has become infected with micro-organisms, *'germs infect the child'* (ca18), although any qualification of how infection occurred is not included. Other comments indicate that the child could be infectious to others, *'could be contagious'* (ca1), although no comments indicate how the infection could be transmitted.

Sickness and micro-organisms are connected (score1)

Eleven children (10.7%) connected micro-organisms to the sick child in alternative statements and eight of these suggested that the child required some type of medication to recover, *'the child was not vaccinated against disease'* (ca49).

5.6.2 Pathogenic micro-organisms and infection

Year 2

Discrimination between pathogenic and non-pathogenic micro-organisms is not evident. The majority of children in this age group consider that all micro-organisms are potentially pathogenic, *'if a germ gets inside you body you shall be ill'* (si1), and illness is an inevitable consequence of contact with micro-organisms. Comments do not indicate that some micro-organisms are more virulent than others, although there is some recognition that the severity of disease, or illness, can vary, *'if a germ gets on you, you will feel a bit ill or very ill'* (si13), and that in extreme cases death is a possible outcome. Specific pathogenic organisms are not named; chicken pox and 'tummy' upsets are the most frequently referred to illnesses. This is not surprising as children of this age will be familiar with these common childhood ailments.

Micro-organisms are thought to be highly infectious and easily transmitted from a sick individual, *'if you go near the sick child you could catch it, germs are horrible they give you a very very bad tummy'* (tb47), or a contaminated place, or an item, *'germs live anywhere, if you have been playing with soil and you lick your fingers you will have a bad tummy'* (tb47), with the inevitable consequence of illness. Illness is thought to occur in the recipient even if the person transmitting the micro-organisms isn't necessarily ill themselves, *'a germ is if you got a drink and somebody says to you, can I have your drink and you don't wipe it and you just give it you will get very poorly'* (si25), which suggests children of this age regard micro-organisms as highly virulent and dangerous.

Diseases are also thought to be readily transmitted, *'if you touch it you get really sick'* (tb34); *'if you go near the baby you will catch germs'* (tb44), these comments do not mention micro-organisms directly, but do indicate some ideas about contagion and modes of infection, although they are rather vague. Everyday experiences rather than learnt facts seem to provide children with ideas about infection, *'it's a bit like nits they jump from one person to another'* (hai40); *'if the child's brother comes near him he will have chicken pox too, I know because I had it* *and my brother caught it'* (tb22), and this can lead to contradictory ideas with regard to infection:

Interviewer	*This lady's got a cold. How do you think she got her cold?*
tb29	*By germs.*
Interviewer	*How did the germs get to her?*
tb29	*Not sure.*
Interviewer	*Do you think all diseases come from germs?*
tb29	*No.*
Interviewer	*What sort of other illness?*
tb29	*Maybe if you were going somewhere and it's outside and it starts raining, that might give you a cold.*
Interviewer	*Have you ever had a cold?*
tb29	*Yeah.*
Interviewer	*How did you get it?*
tb29	*That's when I went on my school trip and it was raining and I didn't have a coat. I only had a jacket with no hood.*

Year 6

Children in this age group know that micro-organisms can be pathogenic, but most comments do not provide any discrimination between the virulence of different micro-organisms, although some children indicate that the extremity of infection can vary, *'some microbes can lead to diseases, or worse, death'* (sj26). A range of common complaints were mentioned; for example, cold, flu, food poisoning, diarrhoea and chicken pox; the only named pathogen was *Salmonella*. Children of this age will be familiar with these illnesses, although what is surprising is that so few mentioned a named microbial disease and that no other diseases were mentioned at all.

A key differentiating factor between micro-organisms appears to be whether they are pathogenic or not; 'bad' micro-organisms cause disease and 'good' micro-organisms have a beneficial function, *'some are good, these protect you from bad germs, some are bad, these are what make you ill'* (haj24); *'the bad ones give you diseases the good ones help you make food and drink like beer, cheese and many more things'* (sj21).This age group will have been taught about beneficial and non-beneficial micro-organisms during Key Stage 2. It appears that these children are making a distinction between the two categories in relation to illness.

Comments indicate that children know that micro-organisms can be transmitted in a variety of ways, *'most are infectious, coughing and sneezing and touching others can spread them'* (sj9); *'they come from raw meat like chicken, they can pass on to people by sneezing, coughing and kissing, they can be passed on at food parties and discos'* (haj40), with illness occurring as a consequence of becoming infected although in a more matter of fact way than younger children suggest.

Other responses suggest that because the child is ill, he is a vector for the disease; he can therefore infect others and is a hazard, *'sick child can make you sick'* (sj30); *'dangerous to go near'* (haj4). These responses do not refer to micro-organisms directly but do indicate that children have some ideas about contagion and infectious disease.

Children know that micro-organisms cause diseases, although seven of those interviewed were uncertain about whether all illness was due to micro-organisms, but the majority could not provide examples and everyday experiences reveal ontological thinking suggesting that children have alternative and contradictory ideas about causes of infection:

Interviewer	*How do you think they got the cold?*
haj77	Um, from like, being, if they get like a virus, then they go out in like the cold air *straight away, or the, yeah, like they go in the cold air straight away. They kind of like catch a cold.*
Interviewer	*Have you ever had a cold?*
haj77	*Yeah! Lots of times.*
Interviewer	*Do you remember how you got it?*
haj77	*Um, I think it's because like after I had like, a shower, I went outside straight away in the cold. Like 'cause I was ill and I had a nice hot shower, then went out in the cold.*

Year 9

Children know that micro-organisms are pathogenic and several comments included the idea that they are parasitic. Others suggest that, *'they attack your immune system and white blood cells'* (ca1); *'with bacteria eats white blood cells, they break down your immune system and make you feel ill with all the germs'* (ca78), indicating that some children in this age group have a more advanced notion about infection even though the comments indicate confused ideas about what occurs at the cellular level.

The difference in the level of virulence between micro-organisms, or the severity of infection, is not commented on by the majority of children, although two of those interviewed offered suggestions about the difference between micro-organisms in connection with virulence, *'Different, 'cause some are like more deadlier that others'* (ca89); *'You can get like, good ones but you can get bad ones and the good, the bad ones are the kind that make germs like, make people ill and things like that'* (ca94).

A variety of illnesses were cited, some which are not caused by micro-organisms, *'cold, flu, stomach ache, cuts and grazes, sick, diseases cancer, leprosy, worms'* (ca63). Children are aware of a wide range of illness, but seem to have simply mentioned every one they could think of and have not discriminated between microbial diseases and others.

Children are aware of various modes of infection, although humans seem to be the main vector either through direct contact, '*um, no some can be caught through the skin, um, through human contact, um because the skin has like, a layer, a mild layer of acid um, and basically this protects from most of your common viruses um, but some viruses can withstand that and it goes through the skin as well*' (ca18), or proximity, '*Um, from someone else I s'pose. Like, from someone else sneezing or coughing near them*' (ca54). Partial understanding about modes of infection is evident, whilst other comments indicate partial understanding about the causes of infection. In this instance, it is the individual who seems to be have been irresponsible and therefore become infected, '*Not all [caused by micro-organisms], but I'd say some. 'Cause some diseases like, when you get things like athlete's foot and things like that, that's like, not your own fault, but it's all down to you. I think*' (ca94). Contradictory ideas about the causes of infection were also indicated in interview comments:

Interviewer	*How do you think she got her cold?*
ca62	*Virus got passed on.*
Interviewer	*How did it get passed on?*
ca62	*Someone else probably coughed in front of her and the germs went in her mouth.*
Interviewer	*Have you ever had a cold?*
ca62	*Yes, I've got one at the moment.*
Interviewer	*And how did you get yours?*
ca62	*Well I don't know actually, cause I was just... I got it on Sunday, I'd been... Oh, I'd been at the beach! And I'd been in the water loads and got a cold cause I got cold.*

5.6.3 Immunity

Year 2

The majority of children in this age group do not seem to be aware of immune responses to infection; only four children indicated that the sick child's symptoms were as a result of a reaction to microbial infection and three brainstorm comments indicate anthropocentric notions of an immune response, '*when a germ comes into your body the blood says hello who are you and the germ replies hello I'm a germ and the blood fights it off*' (hai50).

The photograph of the vaccination did not elicit any comment about acquired immunity. Interview comments suggest it is the vaccine itself acting as a type of medication and is the active agent in disease prevention, '*Well injections, some injections, they take your blood and some injections they put medicine into* *you........ and with the medicine they put it down you and it shoots down the vein, I think, and it comes out and then it all, it sort of like turns into like a little good germ, big good germ, and that fights as well'* (si38). One child indicated a rudimentary idea of acquired immunity, *'in an injection there is some bad germs and lots of good, they put bad germs in because the body can get strong by practising'* (hai61).

Year 6

Only a small number of children (4) stated that the sick child's symptoms were as a result of a reaction to infection, *'the micro-organisms have done something to the child to make them ill'* (sm37), and the responses suggest that children have an unsophisticated notion of immune response.

Vaccinations are regarded primarily as a type of medication to 'get rid of' or 'kill' micro-organisms. The presence of (beneficial) micro-organisms, *'vaccinations have lots of micro-organisms to make or prevent a child from dying or catching a disease'* (sm7), appears to be sufficient to prevent a disease or eliminate pathogenic micro-organisms, *'good germs trying to get rid of bad germs'* (haj44). It is the micro-organisms *per se* that seem to be the active agent in this process, rather than them triggering an immune response, *'this is to prevent bad organisms, sometimes micro-organisms are put into the body to prevent illnesses'* (sm25). Some comments indicate that vaccine confers immunity in a physical manner, *'Um, I think they put something that is a barrier against the micro-organisms so that they can't get through.........Um, something that could tell if the microbes were harmful and could stop them getting in to your system'* (sj11); *'can be made into vaccines to help your body to get an idea of the forces it needs to stop the disease'* (haj59). One child has more advanced ideas about the immune process, *'I think they give you um, some sort of the actual disease and then the antibodies help fight it, but it's not very much, so they um, they make a special type of antibody. A special one that will, if I ever get the disease, then will fight it, it will fight it immediately'* (sj53). The longevity of acquired immunity was also noted by another child, *'Um, I think it's carrying some kind of, um, good micro-organisms that if you do get meningitis it fights it off as much as it can, but it's always in your body just in case um, you do get meningitis'* (haj12), although the majority of children did not comment on the functioning of vaccine; for some children, large numbers of micro-organisms are required for vaccine to be effective.

Year 9

Only one response to the photograph of the sick child indicated that infection would cause a reaction, although the comment does not reveal any ideas about immune response; however, some children do seem to have clearer ideas about immunity, *'Um, my body releases, well, the white blood cells ah, in the blood stream, either release ah, antibodies, which um, destroy the virus, and the copied viruses. Or um, white blood cells engulf the um, the virus. But it also has to stop all the other reproducing cells, which have come from the bloodstream'* (ca18).

The largest group of children (43.7%) responding to the photograph of the vaccination consider it as a type of medication to 'kill' micro-organisms and a further 14.6% regard the presence of micro-organisms in the vaccine as the active agent in this process rather than triggering an immune response, *'a vaccination contains micro-organisms to help fight germs [which cause disease]'* (ca5). However, five children indicated more sophisticated ideas about acquired immunity in response to the photograph of the vaccination, *'vaccinating children gives them a bit of disease to work up their immune system'*, (ca3); *'the injection gives the body germs so the body makes more stuff to get better so the body is immune to the next illness'* (ca89), and similar responses were forthcoming from interviews, *'Yeah, it sort of like, makes your um, body immune to the disease....... Isn't it something to do with, it sort of injects like a sort of, um, it's not as harmful of the disease, into your body, so it learns how to fight it, so if you get it again the body knows how to deal with it'* (ca100), although further explanations about what happens at the cellular level were not forthcoming.

5.6.4 Recovery and medication

Year 2

The majority of children seem to be uncertain about how recovery from illness occurs, although some indicate that expelling, or killing, micro-organisms with, or without, medication is thought to result in instantaneous recovery, *'Well um, I had to bring a tissue to school and I kept on sneezing and funnily like, everything that could get out got out and I um just, became better'* (hai58):

Interviewer	*Do you remember, can you think how you got better from the chicken pox?*
hai61	*Um, it was because my um, Mummy took me to the doctor and the doctor said take um, take this um, take some Calpol and then I took some Calpol and so in the morning it, um, I didn't have it.*

Several interviewees mentioned the idea of 'good germs' in the body, or in medication, which kill pathogens directly, '*well, the good germs that are inside you trying to fight the bad germs and get the bad germs dead'* (hai58); *'Well there's good germs in it (medicine) and when you have it the good germs fight so it's sort of like your fighting someone'* (si38). The notion of a physical fight where part of the body, or good micro-organisms in the body, or in medicine, attack those causing infection seems to be a common explanation of how prevention or recovery from disease occurs.

Their view seems to be that once micro-organisms have been killed, or expelled, a person is returned to health, *'It was because my Mummy got hers from work and then, um, I always stay in my Mummy's bed and then she passed it on to me and then I lost it over to my brother and then, and then my brother lost it over to my Daddy and then my Daddy lost it out of our family'* (hai61). A corollary to this might be that the absence of micro-organisms means that an individual is naturally healthy; health is therefore related to the lack of infection caused by micro-organisms.

Year 6

Children seem to consider recovery from illness occurs as a result of special care or a combination of care and medication:

Interviewer	*How did you get better?*
haj77	*I had like, lots of hot water bottles and my Mum gave me medicine. Per-scripted by the doctor.*
Interviewer	*How did the medicine and keeping warm make you, get you better?*
haj77	*Well the, if like, you have a cold and kind of like, sometimes it makes you feel like you keep on having shivers, so my Mum gave me the hot water bottle to like, make me all cosy and make my tummy feel better. And the medicine helped me like, if I had a headache, it kind of like soothed it down.*
Interviewer	*Do you know what happens inside you as you get better?*
haj77	*Um, no.*

The mechanism of recovery is not clearly understood, although some children indicate that getting rid of micro-organisms is important, *'Well, because your body goes so tired because you um, the bad bacteria is cleaned out and go to the toilet and stuff like that. You need to go to the toilet to get all the bad bacteria out'* (sm17). The removal of micro-organisms is often seen as a fight between good and bad types,' *'I think there might have been good bacteria trying to fight off the bad micro-organisms, or, I'm not sure, but some kind of good micro-organisms trying to fight off bad'* (haj12).

Several children also mentioned the idea of a healthy diet which contain good micro-organisms enabling the body to defend itself against infection, '*Um, eat good nutrient food that have, like the yoghurt that has lots of good bacteria and in, so it feeds, it helps produce… and then the good micro-organisms could maybe multiply and then help the other ones that are trying to fight off the bad ones'* (haj12). The nutritional benefits are not clearly understood and some ideas regarding diet and recovery from infection are clearly folklore:

sm17	*Like, once when I had chickenpox I wasn't allowed to eat chicken*
Interviewer	*Why couldn't you eat the chicken?*
sm17	*Mum- My Gran, she just had this kind of like feeling that you shouldn't eat chicken when you got chickenpox and you should - can only wear red. Dunno why, it's just.*

The majority of this age group consider that antibiotics and vaccinations are antimicrobial agents (Figure 5.68) and some children consider they contain good micro-organisms to remove, or kill, those causing disease, *'jab can make you feel better it's got good micro's in'* (sm17); *'antibiotics is a good source of micro-organisms which fights the bad germs in your body'* (sm31). The comments also suggest that micro-organisms are the active agents and that vaccine and antibiotics contain micro-organisms which attack the pathogens causing disease, '*… got good fighting bacteria'* (sj36); *'micro-organisms to fight bad micro-organisms'* (haj51). The language used is aggressive and confrontational which suggests that the children consider that a pitched battle is taking place between the 'good' and 'bad' micro-organisms.

Other medication is also thought to contain good micro-organisms and in some instances is regarded as akin to antibiotics, '*Yeah, because they (antibiotics) make you well too. They're like Calpol, they've got a good bacterium in them'* (sm17) and reference to a fight between good and bad micro-organisms is again presented:

Interviewer	*So, do you know how you get better?*
haj12	*Um, I have this thing, this medicine called Neurofen that like, goes straight to the pain, must have lots and lots of good micro-organisms that you drink into your body and they go from your throat into all the places where you've got pain and fight off all the bad micro-organisms.*

Year 9

The majority of children interviewed seem to place a high reliance on medication to recover from illness, *'sometimes I like take, take like, not um Paracetamol. I take like Beechams and things like that, 'cause they're good for colds'* (ca94), and several children commented that medication was required by the sick child. Antibiotics were cited as medication for a variety of illnesses including viral infections such as colds. Others suggested that recovery occurred naturally over time, *'I just let it be and eventually, eventually it just went away'* (ca54): *'Ah basically it just got better over time'* (ca18).

Recovery is also thought to be the result of killing the micro-organisms that cause infection either from medication, *'maybe the medicine kills the cold'* (ca78), or from some kind of confrontation with white blood cells, *'Ah, well white cells specially designed to sort of, fight off any bacteria or germs and stuff'* (ca23). The mechanism of recovery is frequently described as a fight, although fewer comments are made about the confrontation between 'good' and 'bad' micro-organisms, comments such as, *'killing bad germs'* (ca94); *'white cells'* (ca23); *'it [medication] fights the bad cells'* (ca62), suggest that knowledge is partial and unclear.

The majority of this age group consider that antibiotics and vaccinations are antimicrobial agents (Figure 5.69). A small number refer to the idea of beneficial micro-organisms as the active agent in antibiotics and others seem to be confused about how antibiotics work, *'they eat the bacteria inside you'* (ca78); *'both have antibodies in'* (ca95); *'if you think about like, a certain shaped passage, it's like a jigsaw puzzle, you can't get any shape to just stick in a jigsaw puzzle picture, so that's just sort of like, how it is with antibiotics'* (ca23). Two of the interviewees appear to confuse other medication with antibiotics, one in the way they work *'same as Beechams I think'* ca94, and the other as being the same thing:

Interviewer	*Have you ever had any antibiotics?*
ca62	*Yes like Ibuprofen and stuff, for headaches, I've had that.*

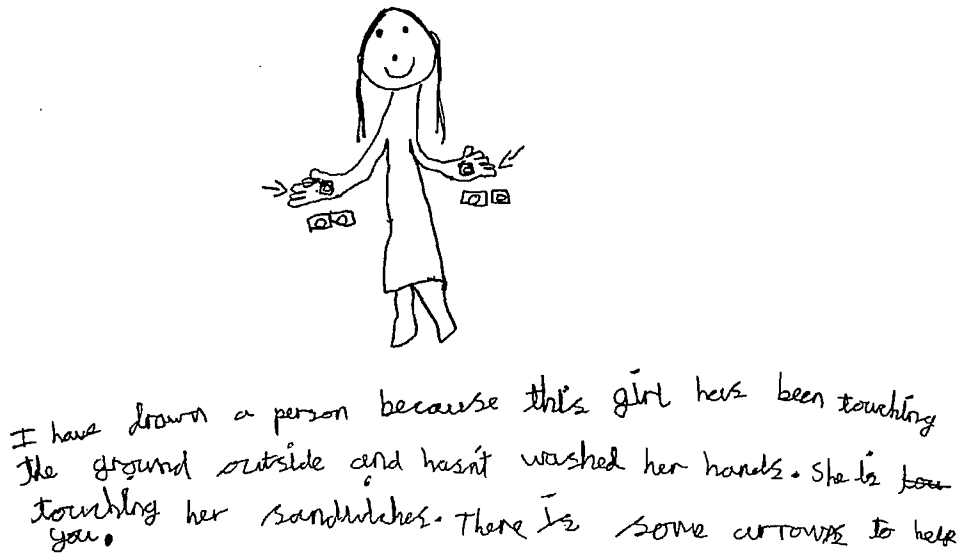
5.6.5 Infection control

Year 2

Comments, for example, *'you can wash them out in the bath'* (hai59); *'you wash your hands so the germs fall off'* (hai56), and drawings (Figure 5.50) indicate that this age group places a high priority on simple hygiene measures to prevent infection. These ideas seem inconsistent with their prevailing notion that micro-organisms are pervasive and highly infectious, *'you can catch them if you bite a piece of cake from your friend'* (si34); *'if you open your mouth germs go in your mouth, germs come from other people'* (si26), and contact causes immediate illness, *'germs live in infected things, germs make you sick when you don't wash your hands'* (tb17). Other forms of infection control are not commonly known and only two children thought that bleach or *Dettol* would be useful in controlling infection.

Figure 5.50

Year 2: Drawings indicating hygiene measures

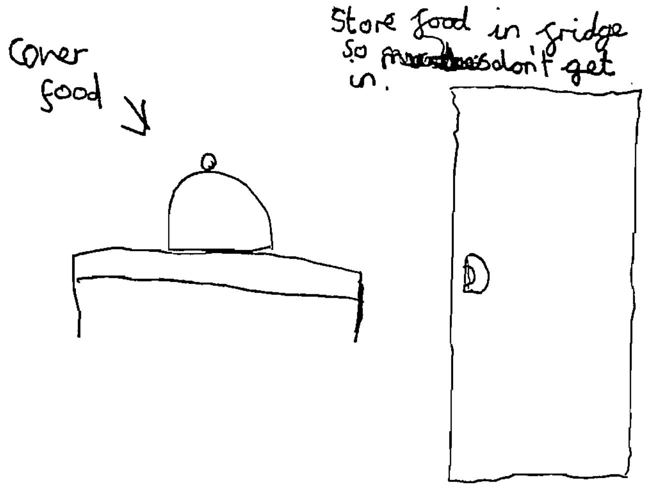


hai55

Year 6

A variety of procedures, which include personal and food hygiene (Figure 5.51), are regarded as a way of preventing infection by this age group, '*you can clean the table tops to not have microbes. You can also become ill because of micro-organisms, you should always wash your hands after using the toilet. You would have to store food in the fridge so microbes can not get inside, from not getting ill from microbes do not cough or sneeze over people or touch or you will catch it*' (sj46). Responses indicate formal learning in this area; for example, several children mentioned specific temperatures that would kill micro-organisms and others indicated that refrigerating or cooking food would prevent contamination, '*microbes don't like hot climates (it kills them) so we boil our water from places where germs are, microbes don't like cold climates so that's why we keep our fridges cold to make our food last longer*' (sj12).

Figure 5.51
Year 6: Drawings indicating hygiene measures



sj46

Bleach is regarded as a substance to remove or kill micro-organisms by the majority of children who made a connecting statement to the photograph (45.6%). Although, 16.0% of Year 6 children suggest that bleach contains micro-organisms, *'it is a nice germ and kills other bad germs'* (sj24), or that they were present in the bleach as a cleansing agent, in this case attributing almost magical properties, *'bleach contains germs to make the room clean and tidy'* (sm7). These alternative ideas may be due to the connection many children made between the vaccination, antibiotics and bleach. Comments such as, *'all help to get rid of or prevent microbes (germs) otherwise you might end up as a sick child'* (sj12), suggest that children consider that all three items have the same effect on micro-organisms, as their mechanisms of elimination are not explored further.

Year 9

Hygiene procedures were not referred to by this age group in brainstorms, or drawings as a way of preventing infection, although interviews revealed that children are aware that certain precautions, for example, washing hands and cleaning food surfaces help to prevent microbial contamination. However, exaggerated ideas about the potential danger they pose was a feature of responses, *'Well, 'cause you can get sort of like, ill from germs and bacteria, for instance, meat, people think that getting one cloth and sort of cleaning it, when they use the same cloth, they think the germs are sort of, gone. But actually, you're spreading it and as you're spreading it, it starts getting worse and worser, so you're just sort of digging a massive hole when you don't realise'* (ca23).

As opportunists, micro-organisms are seen in an anthropocentric manner in exploiting the situation:

ca78	*Oh, they could be on like, when you leave, when you like, make a salad or some kind of meat and you like, chop it up on a board, they're probably there. Like, if you didn't wipe it off with Mr. Muscle, or something.*
Interviewer	*And what are they doing there?*
ca78	*Um, they're probably just like, waiting for something to touch them so they can spread around everywhere.*
Interviewer	*And why would they want to be spread around?*
ca78	*So they can find things to eat.*

Bleach is regarded as some type of antimicrobial agent, 44.7% of children made a connecting statement to the photograph of bleach, '*contain agents that will kill bacteria that is harmful*' (ca53), and three comments make a connection between antibiotics, vaccine and bleach without further exploration of their different mechanisms.

5.6.6 Summaries, progression and overview

A résumé of the findings about disease, health and infection control in relation to micro-organisms is presented below.

Year 2

- Micro-organisms are associated with disease;
- Micro-organisms are thought to cause disease;
- Micro-organisms are considered to be highly infectious;
- Levels of virulence are not recognised;
- Illness is thought to occur as a spontaneous reaction to the presence of micro-organisms in the body;
- Modes of transmission are not clearly understood;
- Contradictory ideas are held about causes of infection;
- Recovery is thought to be immediate after micro-organisms have been killed or expelled from the body;
- Recovery is thought to involve a fight between the pathogenic micro-organisms with parts of the body, 'good germs' present in the body or in medication;
- Very few examples of illnesses were cited;
- Ideas about immunity are not generally understood;
- Simple hygiene precautions are thought to eliminate all micro-organisms and prevent illness;
- Contradictory ideas are held about infection control and the cause of infection;

- Micro-organisms are thought to be dangerous because they cause disease;
- Anthropocentric thinking prevails with regard to micro-organisms as the cause of human illness and reaction to infection and recovery.

Year 6

- Micro-organisms are thought to cause or be associated with diseases;
- 'Bad' micro-organisms cause disease;
- Levels of virulence are not generally recognised;
- Being infected with micro-organisms is thought to result in illness;
- Some modes of transmission are recognised;
- A variety of microbial infections are known;
- Contradictory ideas are held about causes of infection;
- Recovery is thought to involve special care and medication and sometimes a healthy diet;
- Medication is thought to contain 'good' micro-organisms to fight 'bad' ones
- The immune process is not generally understood;
- Vaccinations, antibiotics and bleach are considered as antimicrobial agents which may contain beneficial micro-organisms to fight 'bad' micro-organisms;
- Vaccinations are likened to other medication;
- Specificity of vaccination and antibiotics is not understood;
- Simple hygiene precautions are thought to eliminate all micro-organisms and prevent illness;
- Anthropocentric thinking prevails with regard to micro-organisms as the cause of human illness and reaction to infection and recovery.

Year 9

- Micro-organisms are thought to be associated with or cause diseases;
- Levels of virulence are not generally recognised;
- Micro-organisms are not considered as the only cause of illness;
- Some modes of transmission are recognised and focus on humans as the main vector;
- A variety of microbial infections are known although non-microbial diseases are also attributed to micro-organisms;
- Partial and contradictory ideas are held about causes of infection;
- Recovery is thought to involve medication and the removal of micro-organisms and can be a natural occurrence;
- Immune responses and recovery from infection are not generally understood but some children indicate partial knowledge;

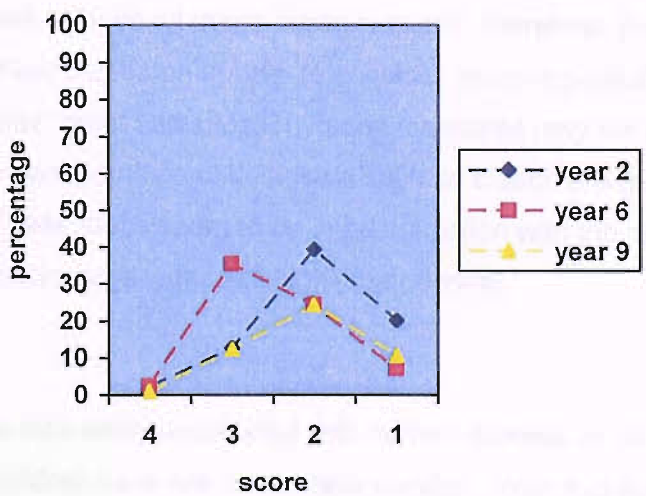
- Beneficial micro-organisms are thought to be the active agent in vaccine, antibiotics and other medication;
- Vaccinations, antibiotics and bleach are considered as antimicrobial agents;
- Vaccinations are likened to other medications;
- Specificity of vaccination and antibiotics is not understood;
- Simple hygiene precautions are thought to prevent microbial infection;
- Anthropocentric thinking prevails with regard to micro-organisms as the cause of human illness, reaction to infection and recovery.

Progression

Micro-organisms and disease

Figure 5.52 shows the trend in children's ideas and indicates that progression slows down and even decreases after Year 6 with regard to ideas about micro-organisms as agents of disease. The symptoms of disease as an immune response to microbial infection are generally not mentioned by any age group, although some Year 2 children have similar ideas to older children (score 4). It seems that the majority of children in all age groups have a fairly unsophisticated idea about microbial infection; illness seems to be a spontaneous and inevitable consequence of contact with micro-organisms. Human diseases were generally the only ones referred to, by all age groups, indicating anthropocentric thinking about microbial disease.

Figure 5.52
Years 2, 6 and 9: Responses to photograph of sick child



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement- see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Micro-organisms are thought to be responsible for all diseases by the majority of Year 2 children, whilst Year 6 and 9 children discriminate between two major groups; those that cause disease and those that do not, often referring to them as 'bad' and 'good' respectively. However, levels of virulence are not generally recognised by any age group and partial, or contradictory, ideas about disease transmission and causes of infection were noted in response from all age groups.

Ideas about recovery from infection varied across the age groups, all children considered that micro-organisms needed to be removed from the body, often involving a fight between 'good' micro-organisms, especially in medication, and those causing the illness. Year 2 and Year 9 also thought that recovery could be a natural occurrence, whilst Year 6 thought that some mediating factor was necessary, such as special care or a healthy diet.

Immunity

Acquiring immunity whether through infection or vaccination is not generally understood, although more Year 9 children appear to have some ideas as a result of teaching. However, their explanations, for example, reference to fights or battles with micro-organisms and white blood cells, seem to be no more sophisticated than younger children's ideas.

Infection control

Year 2 children seem to be more highly aware of hygiene measures to prevent infection compared to Year 9. Responses from Year 2 and 6 consider simple hygiene measures will remove all micro-organisms and, therefore, the danger from infection, whereas Year 9 children appear to consider micro-organisms as a continual and potential threat and simple hygiene measures may not be sufficient to avoid infection. However, antimicrobial agents such as bleach are thought to kill micro-organisms. These ideas seem to be in contradiction with the notion held by all age groups that micro-organisms are highly pathogenic.

Overview

Micro-organisms are frequently associated with human disease by all age groups and the ideas that children have are remarkably parallel. Year 9 children will have been taught more about this topic than younger children and whilst some ideas appear more sophisticated, for example, with regard to immune response, the nature of their understanding does not appear to be anymore complex than that of younger children. They continue to use physical metaphors such as a fight with, or consumption of, pathogens. Furthermore, the majority of children in this age group did not refer to more complex ideas as part of their cognitive repertoire. It would seem that progression about micro-organisms and disease does not occur despite further teaching at Key Stage 3.

5.7 Ecology and ecosystems

Children's thinking about microbial ecology, as well as aspects of decay and cycling of matter are presented, in order to discover children's knowledge and understanding about the activities of micro-organisms in the environment.

5.7.1 Location

Year 2

Connection with humans, dirty, or unhygienic, conditions and animals, were considered by this age group as the main locations for micro-organisms. Children's ideas about where micro-organisms can be found were evident in drawings and brainstorm comments (Table 5.24). Nine of the ten interviewees suggested that micro-organisms would be found in similar locations.

Table 5.24
Year 2: Location of micro-organisms
(n=22 drawings, n=51 brainstorms)

	Percentage of drawings	Percentage of brainstorms
Humans	41.0	49.0
Dirty / unhygienic conditions	36.7	31.3
Animals	31.8	19.6
everywhere	0	11.8
Other	0	0

The data (Table 5.24) shows a strong association with humans as a place where micro-organisms can be found, *'germs live in your tummy'* (hai77); *'you mostly find germs on your hand'* (hai14). Comments from brainstorms and interviews indicate that the micro-organisms are present in, or near humans, to cause harm:

Interviewer	*And what sort of things do they do when they're on your hands and your feet?*
hai61	*Um, they, um, they get inside you, try and wriggle inside your hands and then try and attack the bit that they want on you.*

Dirty, or unhygienic, conditions were also regarded as places where micro-organisms could be found, *'I know they make you poorly, I know they live in dirty places because dirty places make you sick'* (tb2), these included soil, mud or dirt, toilets and sewers. Animals were considered as a location for micro-organisms, *'a* *ladybird is full of germs'* (tb30), and a potential source of contamination to humans, *'wash you hands after petting animals or you will have germs forever'* (tb33).

Drawings and comments, *'they smell like dirty washing and skunks'* (hai20); *'I think germs are dirty things, they make you sick, they are yuk'* (si5), indicate an aversion to micro-organisms and confirm that micro-organisms are thought to be unpleasant and very dangerous due to the threat they pose to human health.

Anthropocentric thinking appears in some children's comments with micro-organisms given free will in making decisions about where they can be found and what they are doing:

hai58	*In the bin, maybe. Um… in the dump.*
Interviewer	*Why in places like the bin and the dump?*
hai58	*Um, I don't really know, um, but it might be because it just… um, they just decide to be in something. They just think 'I want to go'.*
Interviewer	*What are they doing there?*
hai58	*Um, maybe just walking around or sitting until someone eats the bread and gets germs.*

Year 6

Table 5.25 shows the ideas that children stated in drawings and brainstorms about where micro-organisms can be found. Interviews revealed similar ideas; five of the eleven interviewees, discussed an association with dirty or unhygienic conditions.

Table 5.25
Year 6: Location of micro-organisms
(n=28 drawings, n=82 brainstorms)

	Percentage of drawings	Percentage of brainstorms
Humans	53.6	39.0
Dirty / unhygienic conditions	21.4	9.8
Animals	0	4.9
everywhere	10.7	32.9
Other: specific conditions e.g. temperature, food	14.3	25.6

The majority of this age group consider humans to be where micro-organisms are found, *'all over the body'* (haj74); *'they can make you ill', they are all over you'* (haj64), and the association seems to be that they can cause harm, *'they are inside us and everything around us some are good in which they help to mature cheese and yogurt, others are quite bad which may cause us to be ill these germs are on our hands after we go to the toilet so we should wash them afterwards'* (sj57).

The ubiquity of micro-organisms seems to be a fairly well established idea with this age group, *'you might, you could find them anywhere across the world. Could be the cleanest place on the planet and you could still find bacteria there'* (sm17);

'there are millions of micro-organisms, the whole world is covered in micro-organisms, can be found in space e.g. the Moon, they are even found on the body' (haj56). Often the all encompassing 'everywhere' was qualified with examples such as the air, or food and as these comments show, close association with humans is a key idea, *'they can be found everywhere (you probably have got some on you now), if you don't wash your hands you get germs which are micro-organisms'* (haj47); *'microbes are everywhere, 'microbes are on our bodies whether we like it or not'* (sj36).

Although children seem to consider that micro-organisms can be found everywhere, ideas that contradict the notion of ubiquity are also common. In direct contrast to the idea that micro-organisms can be found everywhere, particular conditions are considered necessary for microbial survival, *'they don't like hot over 63° C and cold under -10° C'* (sj20); *'don't like under 6° C, they like warm and moist places'* (sj31); *'don't like too sugary or too salty'* (sj11). These statements are specifically related to the micro-organisms that are connected with human health and cause food spoilage. It would seem that direct teaching has influenced these children's ideas and children seem to have accepted both ideas without requiring further explanation.

Dirty or unpleasant places were not so frequently cited as other locations by this age group, although for some children this is still a strong connection, *'microbes they live on old dirty things, they live on smelly plates, live in your body'* (haj78):

sm31	*Um, sometimes on your skin obviously, and around your house. Near dustbins, things like that. Especially like, when you go like, in mouldy food and in like, gone off drinks, milk, that sort of area. And like, when you go near a, what do you call it, you know where they always, they chuck the trash...... You get quite a lot of micro-organisms there.*
Interviewer	*Why are they in those places, particularly?*
sm31	*Um, because I've always thought they could feed off it. I mean like, they know that loads of humans are there and loads of animals and all that sort of thing, 'cause they, it sort of pulls them nearer.*
Interviewer	*So what sort of things do they, do they do when they're there?*
sm31	*Um like, I've always thought that garbage would give them food. Sort of thing, they would live off that.*

Anthropocentric ideas are found, in particular, in connection with specific conditions for microbial survival as the comments above suggest,
'micro-organisms appear to have free will about where they choose to live and exhibit an emotional response to those conditions.

Year 9

The location of micro-organisms was not commented upon by many children in this age group (Table 5.26). However, data indicate that this age group considers human beings as the most likely place for micro-organisms to be found, *'microbe is a small cell they're always around us'* (ca32); *'microbes often collect on stuff or people'* (ca75), and the notion of causing harm, or disease, was also noted, *'disease, dirt, cuts, infections, food poisoning'* (ca68). Interviews revealed a similar pattern of responses. Seven of the nine children interviewed mentioned connection with humans and three indicated that micro-organisms are associated with humans to cause harm, or disease:

ca100	*Um well, germs and stuff are just really everywhere, you know, in dirty places and stuff. And in the body. And well, all around us.*
Interviewer	*Do you know what sort of things they do?*
ca100	*Well, they can like create diseases and things.*

Table 5.26
Year 9: Location of micro-organisms
(n=1 drawings, n=17 brainstorms)

	Percentage of drawings	Percentage of brainstorms
Humans	100	64.7
Dirty / unhygienic conditions	0	11.8
Animals	0	0
everywhere	0	29.4
Other	0	0

Some children have the idea that they could be found everywhere, although comments were frequently qualified with an association with humans, *'Um, in the garden, um, in... you find them anywhere don't you if you touch? Germs can be passed, like touch a toilet door or something when you go in, and you don't wash your hands afterwards, and you've got all of the germs on your hands, so everywhere really'* (ca26).

Specific places related to humans, such as bathrooms and kitchens, were cited by one child. Three of the nine children who were interviewed mentioned association with human activity, especially food and its preparation:

ca23	*Um, around humans, specially.*
Interviewer	*Whereabouts?*
ca23	*Um, maybe in their, where they eat or cook. Um, on their own hands, like skin, um inside the body itself.*

Dirty or unhygienic conditions were mentioned as places where micro-organisms could be found as the comments above illustrate. The association with humans is a key feature of their comments. Anthropocentric thinking is evident; this age group seems to focus on human beings and their activities as places where micro-organisms can be found.

5.7.2 Summaries, progression and overview

A résumé of the findings about the location of micro-organisms is presented below.

Year 2

- Micro-organisms are associated with humans, dirty places and animals;
- Micro-organisms and where they are found are thought to be dangerous and pose a threat to human health;
- Anthropocentric ideas include the notion of microbial free will and that they cause harm to human health.

Year 6

- Micro-organisms are thought to be found everywhere;
- Micro-organisms are especially associated with humans and can cause harm;
- Micro-organisms require specific conditions to survive;
- Dirty and unhygienic places were also cited;
- Contradictory ideas are held about where micro-organisms can be found;
- Micro-organisms are imbued with human emotions and free will and cause harm to human health indicating anthropocentric thinking.

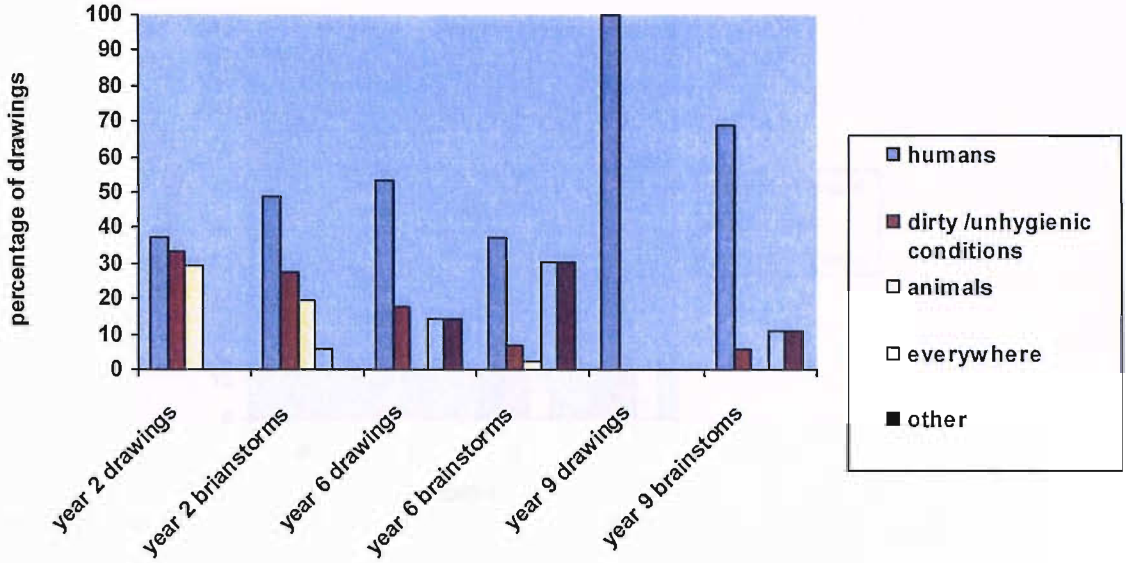
Year 9

- Micro-organisms are associated with humans and their activities e.g. food preparation;
- Micro-organisms are thought to cause harm to humans;
- Dirty and unhygienic conditions are also mentioned;
- The ubiquity of micro-organisms seems to be qualified by specific association with humans;
- Anthropocentric perspective is held about the location of micro-organisms and human health.

Progression

Figure 5.53 indicates that as children get older they increasingly associate micro-organisms with human beings, their activities and as a threat to human health, which suggests a lack of progression and retention of anthropocentric thinking. Progression of ideas seems to occur between Year 2 and 6 about the ubiquity of micro-organisms, although this declines at Year 9. Dirty and unhygienic conditions, or animals, are thought to be sources of infection due to the presence of micro-organisms, are more frequently cited by Year 2. These findings seem to indicate that Year 2 have a more naïve perspective about the location of micro-organisms and the threat they pose to humans than the older age groups.

Figure 5.53
Years 2, 6 and 9: Location of micro-organisms



Overview

Ideas about where micro-organisms can be found seem to focus increasingly on humans as children get older, although all age groups indicate a high association with humans. Ideas held about close association with humans, their activities and the threat micro-organisms pose to human health as a result of their proximity indicates anthropocentric thinking in all age groups. Further anthropocentric ideas which confer emotions and free will to micro-organisms about where they can be found are also held by Year 2 and 6.

5.7.3 Decay

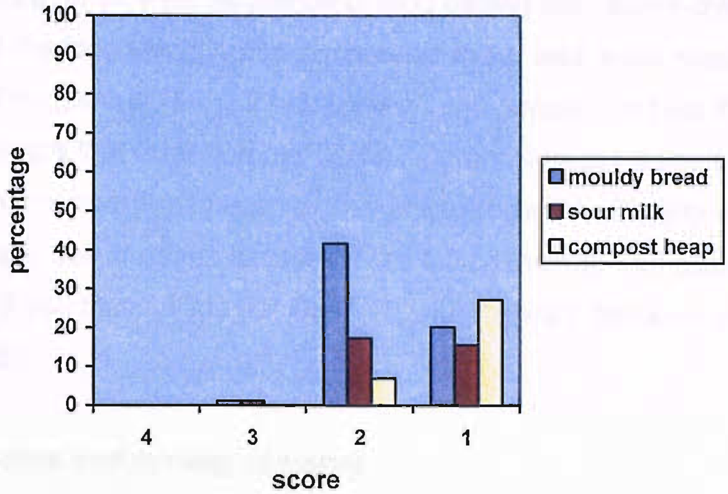
Year 2

Links between micro-organisms and the photographs of mouldy bread, sour milk and the compost heap were made by 42.9%, 18.6% and 6.9% respectively. Only one example of a drawing and a brainstorm comment related to decay. Interviews showed that only three of the ten children interviewed associated micro-organisms with the decaying peach and five did not know what a compost heap was. These findings seem to indicate that children in this age group do not have a good understanding of the connection between micro-organisms and decay.

Responses to photographs (Figure 5.54) and interviews revealed different levels of understanding about the process of decay. The pattern of responses indicates that children seem to be more aware of the connection between micro-organisms and mouldy bread than with sour milk or compost heaps.

Figure 5.54

Year 2: Responses to photographs of mouldy bread, sour milk and compost heap



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

Micro-organisms cause decay (scores 3 and 4)

Very few children (1.2%) consider that micro-organisms cause decay in milk and bread, *'because it [micro-organism] went in it'* (si8), and no child made this connection about the compost heap. None of the children interviewed thought that micro-organisms were a primary cause of peach decay, although five did consider that micro-organisms were present as a result of the peach going mouldy, *'I know this! I know this! I've seen this before! It's where the fruit goes bad so fungus goes on it and it starts eating off of it'* (si38).

Micro-organisms associated with decay (score 2)

Micro-organisms are thought to be present because the bread (41.7%), milk (17.4%), or contents of the compost heap (6.9%), were already decaying rather than being the cause of decay, *'mouldy bread would have germs on it because it is mouldy'* (si49); *'this milk is sour and so has germs'* (si23). A large number of children also qualified their responses about bread and milk and suggest that decaying items pose a threat to human health because of the presence of micro-organisms. Five interviewees considered that the decaying peach was a 'bad' thing, *'because if you eat it (the peach) you will not like it and you will become very, very poorly'* (si38); for some children compost heaps also pose a threat because of the presence of micro-organisms, *'lots of germs in it and might get them on your hands'* (tb20).

Other ideas (score1)

Some children considered that the bread (20.2%) and milk (15.6%) had simply decayed, *'because it has mould on it'* si43; *'this is a glass of milk and it's gone off'* (tb5), although six comments indicated that the food was old, *'because it's been out for a long time'* (hai51). These ideas suggest that children consider decay as a natural occurrence, or as a consequence of food getting old. Some children also considered that the food would not be acceptable to eat and could cause harm, *'very nasty and dangerous'* (tb6); *'it has gone off and people don't eat it because it has different colours that taste horrible'* (tb39). Compost heaps seem to be a repository for micro-organisms because they are associated with dirty and unpleasant things, *'this is germs because it is all dirty'* (hai63), and pose a threat to human health, *'if you touch it you get loads of germs'* (tb38); *'because you could lick it and die'* (hai28).

The decay process and cycling of matter

Children in this age group seem to consider ageing as the main cause of decay:

tb3	*Cause it's very old.*
Interviewer	*So has anything made it go mouldy?*
tb3	*It's got old*

If micro-organisms are thought to be involved they are regarded as a secondary factor after decay has commenced, *'if you leave bread for a long time it turns mouldy and germs bite into it'* (hai6). Other children consider that decay is caused entirely as a result of age or environmental factors.

Children consider that the process of decay in the peach seems to consist of it 'getting rotten', or 'going bad', with accompanying physical changes as a result of leaving it, *'It will just all go, like it is now, it will all go a dark green colour and it will go right around the edges'* (si38). Finally only a small physical entity is thought to remain, *'Nothing cause it's rotten and if it rots, if it all rots, the whole thing would go and start crumbling into dust and then there will be nothing left, well I suppose, a kind of dust'* (tb2). Two children considered the stone would remain and two others thought the skin would be left:

Interviewer	*OK. What will happen to it in the end?*
hai58	*Um, I don't know but, I'm guessing that it's just going to be like, flat skin.*
Interviewer	*So what will happen to all the bits that the peach is made up of?*
hai58	*Um… dissolve maybe?*

The other five interviewees did not have any ideas about what would happen to the peach.

Four of the ten interviewees thought that compost heaps are places where garden and kitchen refuse is placed, *'Yes, it's a place where, I have a little white pot and we* *put all our oranges, skins and all those stuff into it and then when they've sort of half rotted away, I go out and dump them in the compost heap and then they just rot away into sort of muddy grass'* (hai50). Decomposition by micro-organisms was not recognised by any child. Decay and the cycling of matter, including the role of micro-organisms in these processes, does not appear to be understood by this age group.

Negative ideas

Responses show that food decay was regarded negatively and many comments suggest this is due to the food being inedible, or causing illness such as food poisoning, if consumed. The 'bad' food is associated with the presence of micro-organisms, *'sour milk tastes terrible and you will catch hundreds of germs'* (tb33); *'sour milk has germs in and if you drink it you will get sick'* (hai53); *'mouldy bread has germs and its bad for your tummy'* (tb47). All the children interviewed thought that the decaying peach was a 'bad' thing and reasons focussed on the presence of micro-organisms as potentially harmful to humans.

The majority of children who commented about compost heaps consider them to be dirty, or unpleasant places, as a result of being associated with micro-organisms, *'because germs like junk'* (si1); *'compost heaps are smelly'* (tb30); *'the compost heap has germs because it is dirty'* (tb37). Compost heaps, therefore, pose a threat to health, *'a compost heap is dangerous because there might be a baby around which could get very very ill if he ate some dirt'* (si44).

Year 6

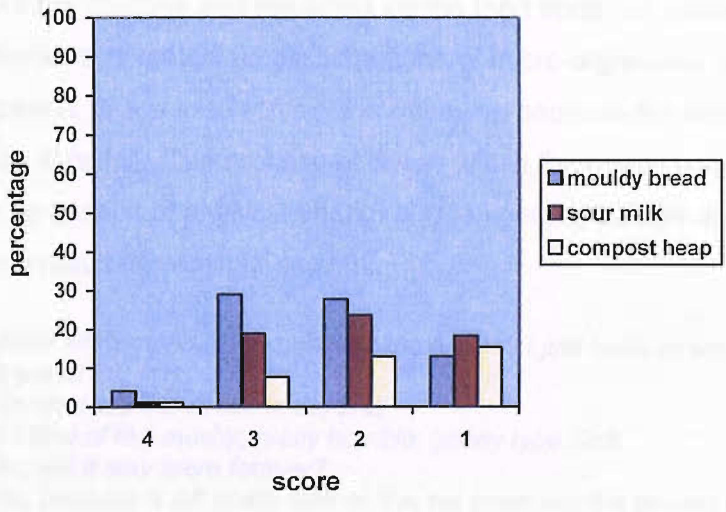
Links between micro-organisms and photographs of mouldy bread and sour milk were made by 60.8% and 43.8% (scores 2, 3 and 4) of this age group, respectively. All the children interviewed mentioned micro-organisms in relation to the decaying peach probe. Thirty-three children (20.1%) made a comment in their brainstorms about decay as a microbial activity although the majority (81.8%) were connected to food spoilage. In contrast, Figure 5.55 shows that very few children 21.9%, (scores 2, 3 and 4) are aware of the relationship between micro-organisms and the compost heap, whilst 62.7 % did not choose the picture, or made no statement. Six of those interviewed either did not know what a compost heap was, or did not know its function.

Different levels of understanding about the process of decay were noted from responses to the concept maps (Figure 5.55) and during interviews. The pattern of responses for mouldy bread and sour milk is similar indicating commonly held ideas about food decay and fewer children seem to be aware of the relationship between micro-organisms and composting.

Micro-organisms cause decay (scores 3 and 4)

Children regard micro-organisms as the causal agent of the decay in mouldy bread (33.1%) and sour milk (20.1%), *'for milk to go sour something makes it go like that and it must of been some kind of bacteria, or germ, or micro-organism'* sj33. Three three of the eleven children interviewed attribute the initial cause of the peach decaying to micro-organisms, although all interviewees considered that micro-organisms were in some part responsible for the peach decay. Statements indicating that micro-organisms were the cause of decay, or rotting, within the compost heap were made by 8.9% of children, *'mud and dead plants are decayed by micro-organisms'* (haj66); *'micro-organisms help to break down waste'* (sm11), and three interviewees thought that micro-organisms were responsible for the decay in a compost heap.

Figure 5.55
Year 6: Responses to photographs of mouldy bread, sour milk and compost heap



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement- see Table 4.6)

Micro-organisms associated with decay (score2)

Micro-organisms were thought to be present because the bread (27.8%), milk (23.7%), or the contents of the compost heap (13.0%) were decaying rather than as the cause of decay, *'micro-orgs like gone off things'* sm4; *'its gone off so germs have got to it'* (sm12); *'a compost heap has lots of micro-organisms in it and around it'* (sm5). The comments present a negative perspective of micro-organisms and a few children commented directly that the micro-organisms were bad, *'because it is* *sour all the good bacteria have failed and it is infested with germs'* (sm7). Other comments indicate that micro-organisms were present in a compost heap because of what is put in it, *'has lots of germs from the germs on mouldy food'* (sj28); *'got germs from the rubbish'* (haj42), making associations with rubbish from items that are already 'infected' with micro-organisms. These comments indicate that children think, at best, that compost heaps are not useful and that they could even be dangerous.

Other ideas (score1)

Children's alternative ideas about food decay included a range of ideas, but many were simply tautological, stating that the bread or milk has become spoilt, *'gone mouldy'* (sj35); *'gone off'* (sj48), suggesting that these children do not have a clear understanding about the causes of decay and that it occurs spontaneously. Comments about the compost heap suggest that it is an unpleasant and dangerous place due to the presence of micro-organisms, *'bad micro-organisms live here'* (haj52); *'gives off a bad smell'* (haj10).

The decay process and cycling of matter

A few children appear to understand that bread (4.1%), or milk (1.2%) is used by micro-organisms as a medium in which to grow and multiply, although further information about the process and the effect on the food does not seem to be understood. Interviews revealed simplistic notions of micro-organisms eating or feeding off the peach, *'It's started rotting and decaying because the microbes have started to feed on it'* (sj11). The process of decay within the peach was thought, by all interviewees, to consist of physical changes, often getting smaller and eventually disappearing as a result of microbial growth:

Interviewer	*What will happen to the peach in the end? If I just keep on leaving it?*
haj77	*It would rot.*
Interviewer	*So what will it look like in the end?*
haj77	*All kind of like mushy, really horrible, gooey type stuff.*
Interviewer	*So, will it stay there forever?*
haj77	*No, because it will finally kind of like, rot down into the ground or something and it won't be there anymore. If you kind of like, put it in the garden it will rot down into the soil. Finally, it'll kind of like go away, it wont be there anymore.*

Three children considered that everything except the stone would disappear and two others thought that the peach (or other items) would simply disappear, *'Nothing. If you, if I left, like, a tree. In like I think it's ten years a tree rots away or something like that'* (sm17).

Microbial activity within a compost heap seems to result in the contents being broken down, '*both sewage and compost are broken down by microbes*' (sj4); '*microbes rot down things on the heap*' (sj57), with an end result of compost or soil, which is good for plant growth:

sm31	*Well, I've always thought, yeah, micro-organisms and germs would definitely be there. Because I know that manure is quite a good thing, so maybe they eat it, well change it by landing there, living there for quite a long time, it's changed into this healthy soil sort of thing.*
Interviewer	*So is that a good thing or a bad thing?*
sm31	*I think it's a good thing...'Cause like, plants can grow and the trees, the trees have better soil which it needs like.*
interviewer	*Do you know how it all gets to be better soil?*
sm31	*No.*

The cycling of matter seems to be understood by a few children at a simplistic level of enriching the soil. Other beneficial outcomes of decay were thought of as a cleaning up process so that the world would not become overloaded with litter from dead plants and animals, '*they rot dead animals, humans and plants so they don't get in the way*' (sj43):

sj11	*Um yeah, in bodies, dead bodies and in Autumn when all the leaves fall cause otherwise there'd be lots of leaves everywhere.*
Interviewer	*Why is it particularly a good thing the decaying and rotting?*
sj11	*Um, because then everything is clear and it, the soil can be used for everything to start again.*

Three of the eleven children interviewed consider that the peach decays as a result of a combination of environmental factors and microbial activity, '*Well the mould has gone over it because you've left it for a couple of weeks and you haven't ate it. And the um fungi has started to grow*' (sm17). Comments about environmental conditions, or age, as an additional factor in causing bread (6 comments) and milk (4 comments) to decay, '*they (mouldy bread) have been left out for a few days and micro-organisms have got to them*' (sj54); '*micro-organisms usually grow in damp things and out of date things*' (sm34), indicate that these children have some ideas about the conditions for microbial growth in the decay process.

However, some children refer to environmental conditions, or age, as the sole cause for decay in bread (6 comments) and milk (5 comments), '*from not being chilled properly*' (sj28); '*because it has gone stale and out of date*' (sj6). Sell by dates are a prevalent part of children's everyday awareness of food and it is not surprising that some children made this type of response.

Negative ideas

The majority of specific comments indicating that decay in food was regarded negatively connect this to micro-organisms making bread, or milk, inedible, or causing illness such as food poisoning if consumed. The majority of brainstorm comments about decay focus on the effects that contaminated food will have on humans in causing illness and disease, *'bad ones make is ill and put mould on our food'* (sj32); *'they make things go mouldy and if you eat it your tummy will hurt'* (sj42). Eight of the eleven children interviewed thought that the decaying peach was a 'bad' thing. Reasons focussed on microbial growth and reproduction as a potential hazard to human health, *'I think that's bad because the, if that's bad fungi on it they could like, grow stronger and move onto something else and spread a disease by this'; cause if it's just a tiny bit of mould that you can't see, you could bite into it and eat it, you could like spread a disease inside yourself'* (haj12).

Negative ideas about micro-organisms also feature in children's ideas about compost heaps suggesting that it is dirty, unhygienic and potentially a dangerous place because of micro-organisms, *'could spread germs'* (sj30); *'full of bad micro-organisms'* (haj8); *'it's a dirty place and micro-organisms like dirty places'* (sj49); *'bad micro-organisms live in here'* (haj52). Three of those interviewed thought that a compost heap was not useful and a potential source of infection, *'Um, if it's like, in your garden then I think it's a bad idea because like, um like, well, they gather and if you kind of like lose something and you think it's in there and like go through it and you get all germs in your hands'* (haj77).

Year 9

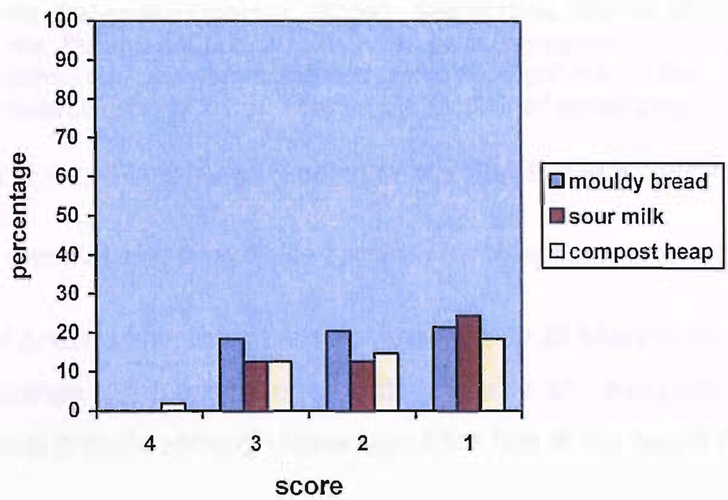
Figure 5.56 shows that links between micro-organisms and photographs of mouldy bread, sour milk and the compost heap were made by 38.8%, 25.2% and 29.1% (scores 2, 3 and 4) of this age group respectively. Eight of the nine children interviewed mentioned micro-organisms in relation to the decaying peach, although only 3 children made a comment in their brainstorms about decay as a microbial activity and two of those concerned food spoilage.

Different levels of understanding about the process of decay were noted from responses to the concept maps (Figure 5.56) and during interviews. The pattern of responses for each item is similar indicating commonly held ideas about decay, although a very high proportion of this age group did not provide a proposition or include the photograph in their concept maps.

Micro-organisms cause decay (scores 3 and 4)

Micro-organisms are considered to be the causal agent of decay in mouldy bread (18.4%), sour milk (12.6%) and compost heaps (14.5%), *'micro-organisms make the bread go mouldy'* (ca86); *'germs make the milk sour'* (ca11); *'micro-organisms break down the stuff in the compost heap'* (ca58). Although, only two children made a more sophisticated comment about decay and both were in connection with the compost heap, *'biodegradable - fertilises soil'* (ca38); *'waste products help plants grow'* (ca76), indicating that these children have a basic idea about decomposition and the cycling of matter. Six of the nine children interviewed attributed micro-organisms as the initial cause of the peach decaying.

Figure 5.56
Year 9: Responses to photographs of mouldy bread, sour milk and compost heap



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

Micro-organisms associated with decay (score2)

Micro-organisms were thought to be present because the bread (20.4%), milk (12.6%), or contents of the compost heap (14.6%) were decaying rather than as the causal agent of decay, *'there is bad bacteria which is making this bread mouldy'* (ca90); *'there are germs in sour milk'* (ca40); *'compost heap has germs in'* (ca97). Four comments related to the mouldy bread and milk, indicating that the micro-organisms are not beneficial, although only one comment about the compost heap evoked a negative response about micro-organisms, *'lots of germs in- both [sewage works] stink'* (ca34).

Other ideas (score1)

Alternative ideas about decay were stated by 21.4% (bread), 24.3% (sour milk) and 18.4% (compost heap). A range of ideas were presented and many were tautological stating that the bread and milk has gone mouldy, or gone off, *'gone bad'* (ca34); *'gone off food'* (ca65), and several related this to age, or environmental conditions, *'when bread is left too long it goes mouldy'* (ca91). These children seem to consider that micro-organisms do not cause decay but that decay occurs spontaneously, or as a result of age. Comments about the compost heap suggest that it is unpleasant and dirty due to the presence of micro-organisms, *'contains germs because it is dirty'* (ca109).

The decay process and cycling of matter

No children specifically indicated that they understood that bread, or milk, is used by micro-organisms as a medium in which to grow and multiply, although interviews suggest that children understand that the peach is being used as a medium for microbial growth:

ca94	*It's like, gone all mouldy. Rotted. Sort of thing. It's not all the way, yet. But like, the um, like the bad like, when I was saying earlier, you get good germs and bad germs, the bad germs have got like, all bad. Like um, overtook sort of thing. They've like made it all go minging and mouldy.*

And the notion of micro-organisms feeding off the peach was a common response:

ca54	*Um, it's being used by the bacteria. It's being eaten away alive.*

The process of decay within the peach was thought, by all interviewees, to consist of a physical change to the peach, often getting smaller and disappearing as a result of microbial growth, although ideas about the fate of the peach were not stated:

ca100	*It'll probably just sort of disintegrate, it'll just probably, the whole thing will probably just mould, or rot away.*
Interviewer	*Will there be anything left?*
ca100	*Well, you'll probably have remains of it, like, the bacteria and stuff.*
Interviewer	*And what will happen to the peach?*
ca100	*Probably be, just, they'll just, it's all rotting away really.*
Interviewer	*Do you know where they go?*
ca100	*No.*

Three children considered that everything except the stone would disappear; reasoning that it was too hard and therefore would not rot. Two others thought that the peach would disappear because it was transformed into micro-organisms.

Microbial activity within a compost heap seems to result in the contents being broken down or converted by microbial activity into compost, *'micro-organisms break down the stuff in the compost heap'* (ca58); *'micro-organisms turn rubbish into compost'* (ca43); *'microbes eat food and then in the process turn it into compost'* (ca53). The process is thought to enrich the soil and produce nutrients for plants to grow and this seems to be the extent of any explanation, '*Well, well it's making like, the compost which makes it more fertile for growing plants*' (ca18):

ca54	*Um, waste things are broken down, to be used as, um, a fertilizer for the soil*
Interviewer	*Do you know how that happens?*
ca54	*From, well from bacteria.*
Interviewer	*What sort of things do they put back in the soil? Do you know?*
ca54	*No, I don't.*

The cycling of matter seems to be understood by a few children at the simplistic level of enriching the soil through composting organic matter. Even personal experience, for two children in this age group, does not seem to increase their understanding:

ca94	*Oh, yeah, it um, that's all like, it's good then, like it's um, that's all the like, germs and things like that, but it's good sort of germs. It's like all the, 'cause my Grandpa's a bit of a gardener. And um, it's got like, loads of good micro-organisms.*
ca62	*Um, I should know this my mum's got one. Isn't it like good for the... good for something, its like... it's like um... something to do with the environment or something. I think it's so that the food doesn't get put on the other tip and it will all disintegrate and get funny so they put in the thing. I don't know.*

Environmental factors in conjunction with microbial activity seems to be understood by four of the nine interviewees as a factor in the decay process and one child seems to understand that the micro-organisms are commensal organisms:

ca18	*Ah, no, basically the moisture has enabled the fungi to grow, right, so basically it was like there to start with but the conditions were right for the fungi to grow.*
Interviewer	*So fungi were already on the peach?*
ca18	*Yeah.*

These children have some ideas about optimum conditions for microbial growth in the decay process. However, concept map comments, bread (7) and milk (2) indicate that others consider that environmental conditions or age alone cause decay.

Negative ideas

Decay was not commented upon by the majority of children in this age group as a negative microbial activity, although seven of those interviewed thought that the peach's decay was a bad outcome because it made the peach inedible, but they did not relate this to the possibility of illness.

Compost heaps are generally thought of positively as somewhere to break down waste and provide nutrients for the soil.

5.7.4 Summaries, progression and overview

A résumé of the findings about decay and the cycling of matter in relation to micro-organisms is presented below.

Year 2

- Micro-organisms are associated with food spoilage;
- Microbial role in decay is not generally recognised, micro-organisms are thought to have a secondary role, if any;
- Decay is thought to occur as a result of age and is a natural event;
- Decay is considered negatively because of microbial presence which results in illness;
- Decay is thought to result in items getting smaller but a physical entity remains;
- Compost heaps are thought to be dirty and dangerous because of the presence of micro-organisms;
- Microbial role in decomposition within compost heaps is not understood;
- Cycling of matter is not understood;
- Anthropocentric ideas are held relating to the danger micro-organisms pose to human health.

Year 6

- Micro-organisms are associated with decay;
- Micro-organisms can cause decay;
- Micro-organisms are closely related to food spoilage, they cause decay or are present because of decaying matter;
- Other examples of decay are not generally understood;
- Decay is considered negatively because of microbial presence which results in illness, but can have a beneficial 'cleaning up' outcome;
- Compost heaps are thought of as dirty or dangerous because of the presence of micro-organisms;
- Decay results in items changing physically and eventually disappearing although some parts e.g. those that are thought too hard to rot remain;
- Cycling of matter is not generally understood and only at a simple level where the decay results in enriching the soil;
- The combination of microbial activity and physical conditions to enable microbial growth is not generally understood;

- Decay can be a spontaneous occurrence or has an environmental or physical cause;
- Anthropocentric ideas are held about personal health and food spoilage and compost heaps.

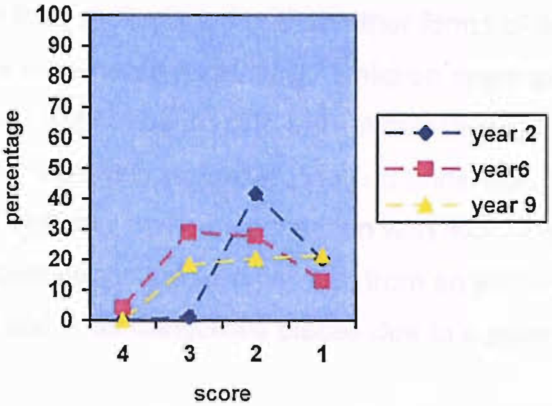
Year 9

- Micro-organisms are associated with decay;
- Micro-organisms can cause decay;
- Microbial activity in decay is thought to consist of an item being 'eaten' and more sophisticated concepts not mentioned;
- Decay is thought to result in items changing physically and eventually disappearing although some parts e.g. those that are thought too hard to rot remain;
- Cycling of matter is not generally understood and only at a simple level where the end products of decay are compost or nutrients for the soil;
- Compost heaps are thought to be useful as a place to rot down waste and provide nutrients for the soil;
- The combination of microbial activity and physical conditions to enable microbial growth is not generally understood;
- Environmental factors alone or age may cause decay;
- Negative ideas about decay are not apparent although some children retain negative views about compost heaps;
- Anthropocentric ideas are not evident.

Progression

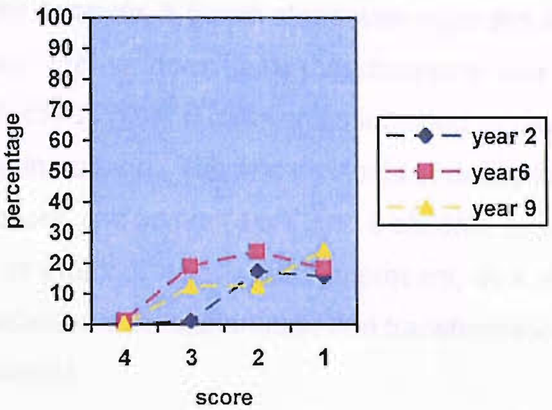
Figures 5.57, 5.58 and 5.59 show the trend in children's ideas and indicate that some progression about microbial causes of decay occurs between Year 2 and 6, although this does not continue to develop and in fact seems to decrease between Year 6 and 9, apart from a slight increase with respect to compost heaps. Alternative ideas, for example, that items will decay 'naturally' as a result of time also seem to stay at a similar level across the age groups indicating that certain ideas persist despite formal teaching or extended personal experience.

Figure 5.57
Years 2, 6 and 9: Responses to photograph of mouldy bread



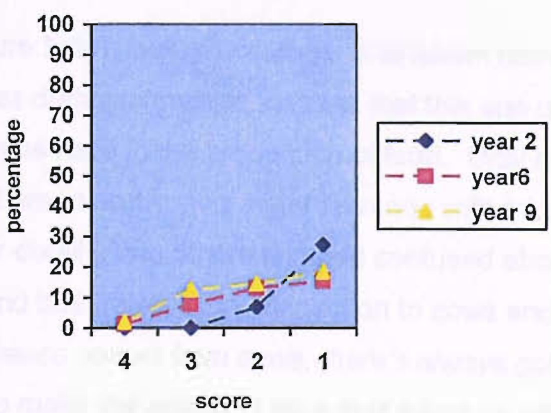
(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-seeTable 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.58
Years 2, 6 and 9: Responses to photograph of sour milk



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.59
Years 2, 6 and 9: Responses to photograph of compost heap



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Overview

All age groups associate micro-organisms with decay to some extent, although Year 2 and 6 focus on food spoilage rather than other forms of decay. It is not surprising that decay is considered negatively. Children seem to have an innate notion that decayed food will not be good to eat. Whilst they are probably unaware of the dangers of such things as mycotoxins, they do understand that it would be unwise to eat the food and they make a connection with micro-organisms as a threat to health. Compost heaps are also viewed, from an anthropocentric perspective by Year 2 and 6, as dangerous places due to a potential risk from microbial infection.

The role of micro-organisms in decay is not generally well understood and few children seem to know, even at a basic level, that micro-organisms break down organic matter. The conservation of matter is not generally understood. All age groups considered decaying items will disappear with, or without, microbial activity, although some items, for example, a peach stone was regarded as too hard to decay and would remain. Furthermore, items that disappear was regarded as a beneficial outcome of decay by Year 6 children as it helped to clear the environment of such things as leaves in autumn. The end products of decay in the compost heap were 'soil' or 'compost' and some Year 6 and 9 children understand that the soil would be enriched, or that 'nutrients' would be present, as a result of decay, although this was the extent of their explanation and transformation into inorganic products was not considered.

5.8 Technological applications

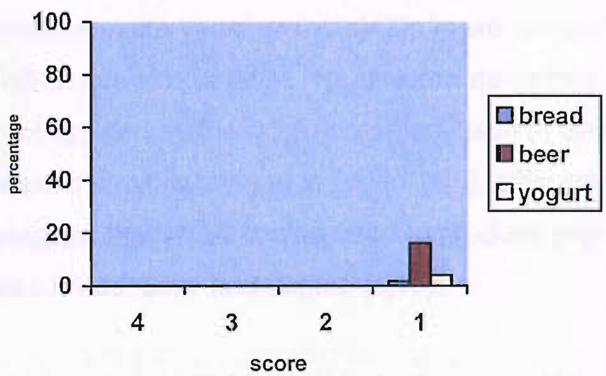
5.8.1 Food

Year 2

Concept map data (Figure 5.60), lack of drawings, brainstorm comments and responses to food probes during interviews indicate that this age group is not aware of the role micro-organisms have in the production of food. Only one of those interviewed thought that bread and yogurt might be made with micro-organisms, but could not provide further detail. Two others seemed confused about microbial involvement with food and both related the connection to cows and milk production, *'Well, I think because cheese comes from cows, there's always got to be germs helping the cow inside to make the milk, so I think that might be with the cheese. Yoghurt? I'm not sure about the yoghurt. I just realised it has milk on it and milk is with cheese as well and germs are helping that. I don't think it has anything to do* *with the source. I don't think so'* (si38); *'Um, they use it from milk and sometimes the milk hasn't been cleaned properly and it um, and it might get some of the cow's germs, or the goat's germs. Whatever cheese it is'.* (hai61). The comments seem to indicate some fragmented knowledge about ruminants and pasteurisation, although the ideas are confused and the connection with micro-organisms is not clear.

Perceiving micro-organisms as harmful led three interviewees to exclude them from food manufacture, *'Um, because if germs if germs actually made that food, when you have it, it will make you ill'* (si9). Reasoning about yogurt indicates similar ideas, *'not germs'* (hai26), and ideas about micro-organisms and beer indicate a negative view of micro-organisms. Fourteen comments (50%) suggest that beer is bad for you and this is due to an association with micro-organisms, *'I think beer is germs because it makes you drunk'* (hai3); *'beer is a germ because it is alcoholic and alcoholic drinks can make you drunk and very dizzy'* (hai 58). These ideas present an anthropocentric view, especially in connection with the danger micro-organisms pose to human health.

Figure 5.60
Year 2: Responses to photographs of bread, beer and yogurt



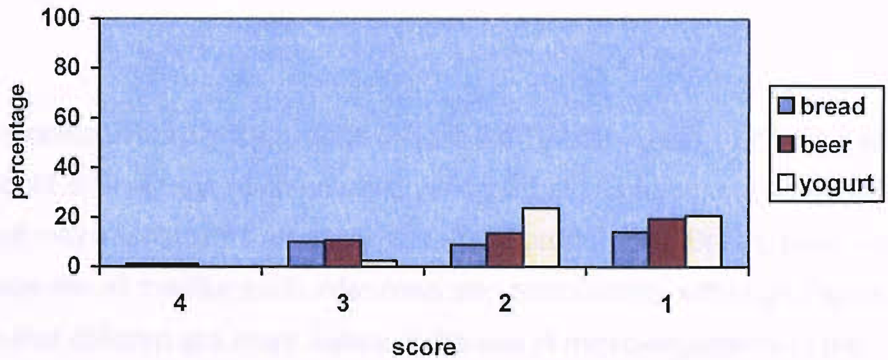
(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

Year 6

The role of micro-organisms in food production seems to be understood by a substantial minority of this age group, Figure 5.61 indicates that, 20.2%, 25.5% and 26.1 % of children (scores 4, 3, and 2) made a connection with micro-organisms and bread, beer, yogurt respectively.

Drawings included 6 examples of association with food and there were 21.3% brainstorm comments about food production, *'not all microbes are harmful to* *humans, e.g. yeast, yeast is used to make bread dough, some microbes are used to make beer, some microbes are used to make yogurt and cheese'* (sj18). Seven of the eleven children interviewed thought that micro-organisms were connected with food production in some way. The foods that were cited most commonly were bread (11), beer (15), cheese (13) and yogurt (11).

Figure 5.61
Year 6: Responses to photographs of bread, beer and yogurt



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see table 4.6)

Only 1.2% (score 4) of this age group recognised that the metabolic activities of micro-organisms are capitalised on in bread and beer manufacture, *'yeast in it to make it rise and microbes make yeast grow'* (sj47); *'make alcohol'* (sm1), although explanations were left at this simple level. No children described what happens in yogurt. Yeast was recognised as the micro-organism used in bread and beer (score 3 and 4), *''yeast is a microbe used in bread'* (sj9), although several comments (6.5%) suggest that yeast is also used to produce yogurt, *'yeast is a microbe; yeast makes bread, beer and yogurt'* (sj17).

The majority of responses (score 2) indicate that micro-organisms are used in food production, and many of the responses connected all three photographs, *'made with micro-organisms'* (sj50). These statements are simple and no further explanation of what, or how, the micro-organisms are employed was made.

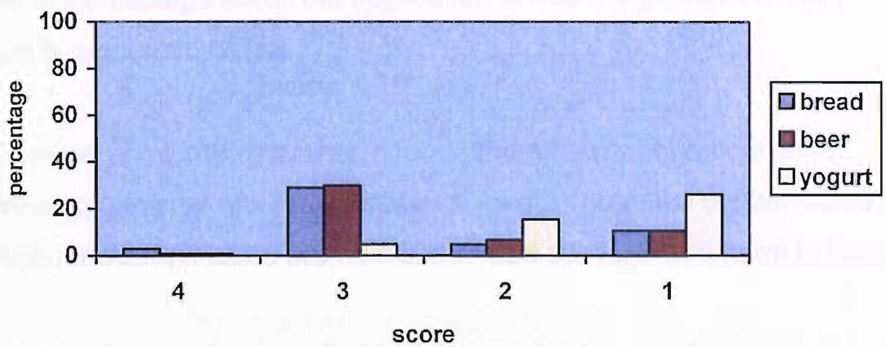
Alternative ideas (score 1) suggest association with micro-organisms was due to contamination in some way, *'bread is on the table but the table's got germs so the bread gets germs as well'* (sm32); *'the beer could have someone else's micro-organisms on it'* (haj 50). Four interviewees also held similar negative ideas about micro-organisms in relation to food, *'Yeah, because like, the Cheddar, um, like, people touch it and like, if they don't wash their hands, they kind of like get all germs in the Cheddar. Because they kind of like, pack it. Sometimes they hand* *pack it, sometimes they do it by machine, but they still put the Cheddar on the conveyor belt, with their hands* (haj77).

Other concept map statements (7.1%) suggested that micro-organisms are present in beer and that their presence is detrimental to health, *'beer has bacteria in it and it damages your health'* (sm15); *'germs can be caused by beer which causes heart disease and is a bad source of germs'* (sm31), indicating a negative view of micro-organisms.

Year 9

Data from concept map photographs (Figure 5.62), interviews (100%) and to a lesser extent brainstorms (6 comments) indicate that this age group is generally aware that micro-organisms are involved in food production. Bread, beer, yogurt and cheese are all mentioned in interviews and brainstorms, although Figure 5.62 indicates that children are more aware of the use of micro-organisms in the manufacture of bread and beer than yogurt.

Figure 5.62
Year 9: Responses to photographs of bread, beer and yogurt



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

The level of responses indicates that the processes involved in the manufacture of these food products are not clearly understood. Very few children, 2.9% for bread, 0.9% for beer and 0.9% for yogurt were able to indicate any further information about microbial activity in their production, *'yeast in bread makes it rise'* (ca3); *'yeast in beer gives it the alcohol and a strong taste'* (ca3), these comments came from the same person and indicate a basically sound level of understanding. All the interviewees were either uncertain about what happens or seem confused about some, if not all, of the processes:

Interviewer	*So we've got some brown bread.*
ca18	*OK. Which is made out of yeast.*

Interviewer	*how does the yeast work?*
ca18	*It raises the bread.*
Interviewer	*How does it do it?*
ca18	*Um... I don't actually know what it does to get to raising the bread. Ah, yeast is also in the beer... so, um, the yoghurt, well it's basically um, ah, milk gone mouldy and ah, basically it is full of bacteria which is good for the digestive system.*
Interviewer	*What about cheese?*
ca18	*Ah, the cheese again is the next stage after yoghurt that, well actually it's the next couple of stages after yoghurt and ah, basically again, it's because the milk's gone mouldy.........The milk's gone off.*
Interviewer	*When it's gone off, what do you actually mean by that?*
ca18	*Um, it means that um, enough, I don't know......Yeah, it, it gradually, takes a while for the milk, because the bacteria do something to it, which I'm not sure about.*

The biggest response (score 3) indicates that about a third of this age group know that yeast is associated with the manufacture of bread and beer and a high proportion of these children (65.6%) made a link to both food products. Bacteria were less frequently cited (4.9%) as the micro-organisms used in yogurt production and a common misconception (score 1) seems to be a connection with sour milk, *'sour milk gets formed into yogurt'* (ca77).

5.8.2 Summaries, progression and overview

A résumé of the findings about the application of micro-organisms in food production is presented below.

Year 2

- The use of micro-organisms in food production is not recognised;
- Micro-organisms are associated with food as potential contaminants;
- Anthropocentric ideas are held about food spoilage and harm to humans.

Year 6

- Microbial use in food production is recognised by a substantial minority;
- The processes involved are not generally understood and ideas about microbial activity are simple;
- Ideas that micro-organisms are associated with food as potential contaminants are presented;
- Anthropocentric ideas are held about food spoilage and harm to humans.

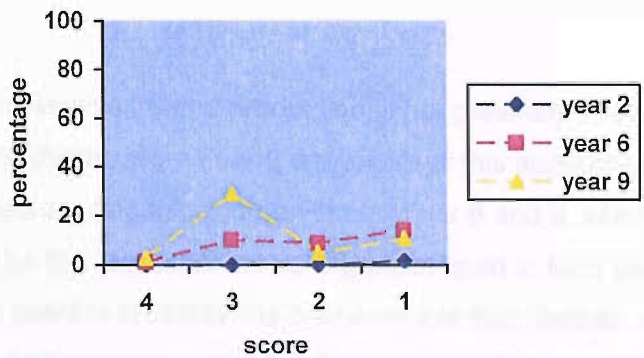
Year 9

- Microbial use in food production is understood;
- The processes involved are not generally understood and ideas about microbial activity are simple;
- Ideas that micro-organisms are associated with food as potential contaminants are presented;
- Anthropocentric ideas are not evident.

Progression

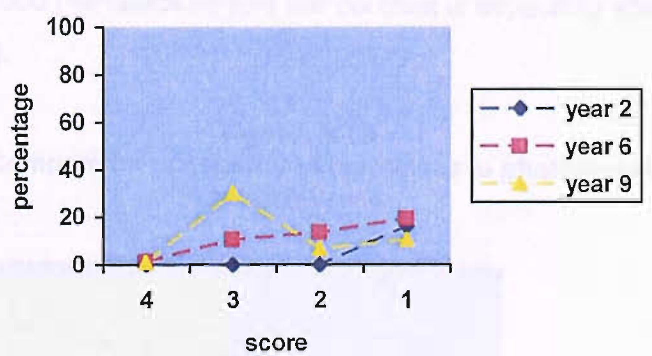
Figures 5.63, 5.64 and 5.65 show the trend in children's ideas and indicate that progression occurs across all age groups with regard to the use of specific micro-organisms in food production, although there seems to be a greater awareness of an association with food and micro-organisms generally in Year 6 compared to Year 9 (score 2). More sophisticated ideas; for example, exploitation of particular microbial metabolism does not seem to increase with age and alternative ideas, such as micro-organisms being present as contaminants in the food rather than as beneficial are retained by all age groups.

Figure 5.63
Years 2, 6 and 9: Responses to photograph of bread



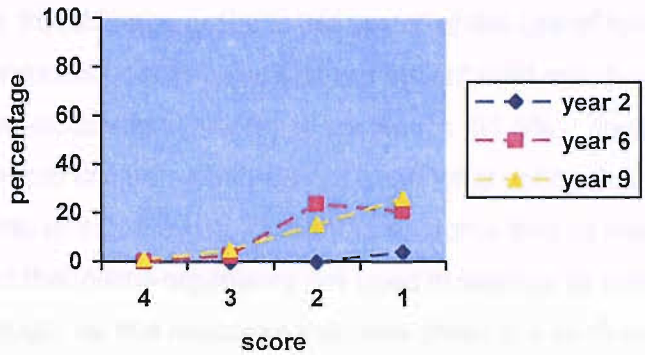
(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.64
Years 2, 6 and 9: Responses to photograph of beer



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.65
Years 2, 6 and 9: Responses to photograph of yogurt



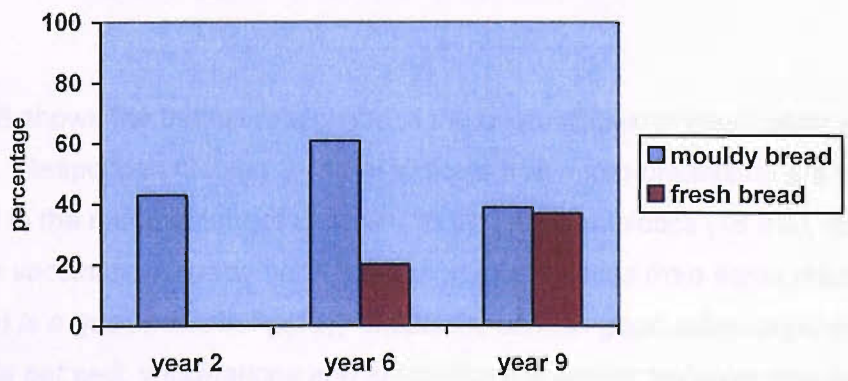
(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Overview

The use of micro-organisms in food production is not generally known by Year 2, although Year 6 and increasingly Year 9 are aware of this application. Yeast is the most commonly cited specific micro-organism by Year 6 and 9, which suggests that yeast is thought to be the 'universal' micro-organism used in food production. This is not surprising as yeast is probably the only example that children will have had any experience of, particularly in school and especially in relation to practical work.

Micro-organisms were also thought of as potential contaminants of food, which indicates a negative view of micro-organisms and this view would seem to be generally held by all age groups given the much greater response rate to decaying food compared to food manufacture and the contrast is especially sharp in Year 2 and 6 (Figure 5.66).

Figure: 5. 66
Years 2, 6 and 9: Comparison of quantity of responses to photographs of fresh and mouldy bread



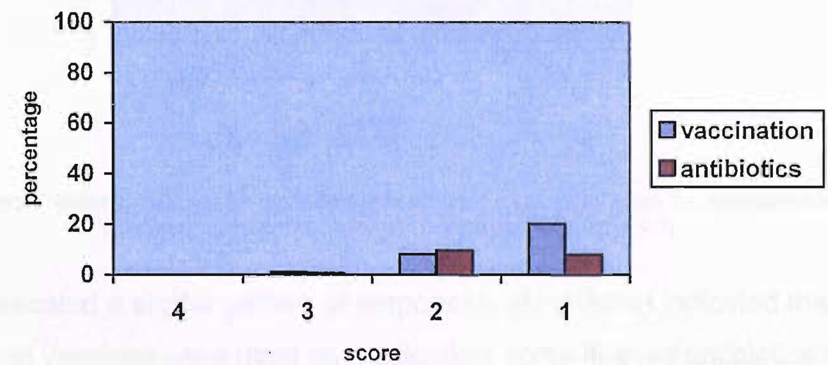
5.8.3 Medical

Year 2

Figure 5.67 shows that this age group is not aware of the use of micro-organisms in the production of vaccine or antibiotics and the majority did not choose the photographs of the vaccination (77.5%) or antibiotics (81.5%). Responses from interviews indicate that children either do not know what antibiotics (8/10), or vaccines (6/10), are, or that they are thought to be some kind of medication. Two children suggested that micro-organisms are used in vaccine to provide some kind of immunity. Although, as this response indicates ideas are confused about the nature and purpose of vaccine, *'Um, because um, they um, every so often you have to have them because they need to check your body to see if it's going well and again they put some good um, liquid that's got um, germs and some bad ones too, from make it practice, um, practice fighting them'* (hai61).

Figure 5.67

Year 2: Responses to vaccination and antibiotics



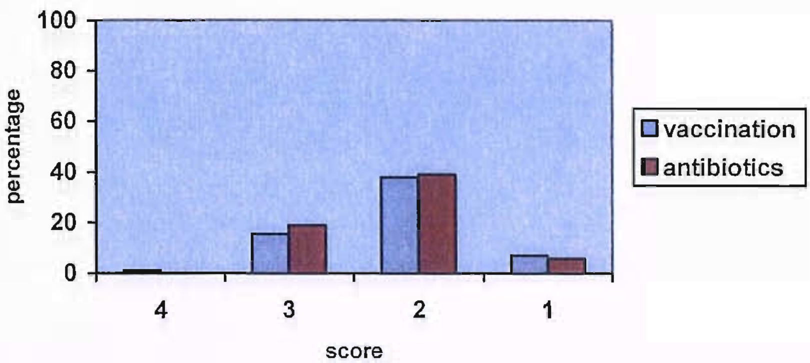
(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

The commonest overall response to the photographs of the vaccination and antibiotics (score 2) also indicates that vaccine and antibiotics are thought to be medication that combat micro-organisms or the disease they cause.

Year 6

Figure 5.68 shows the overall responses to the photographs of vaccination and antibiotics. Responses (scores 3 and 4) indicate that micro-organisms are thought to be used in the manufacture of vaccine (16.6%) and antibiotics (18.9%), *'someone is having a vaccination to stop her from having a bad illness from some microbes, a vaccination is a good microbe'* (sj10); *'antibiotics contain good micro-organisms to help people get well, vaccinations and antibiotics are similar because they help people get well'* (sm7). However only two children (1.2%) provided information about the production of vaccine, *'vaccinations are harmless microbes that cure* *diseases inside humans'* (sj13). Antibiotics were not commented upon at all. The largest responses (score 2) show that these children considered that vaccine and antibiotics are used as medication to kill, or remove, micro-organisms that cause disease, rather than knowing that micro-organisms can be used to benefit people. Responses (scores 4, 3 and 2) indicate that over half this age group understands that vaccine (54.5%) and antibiotics (58.0%) can be used medically rather than knowing about the application of micro-organisms in the manufacture of these products, *'the sick child would probably have a vaccination and taking antibiotics to heal his sickness'* (sj57).

Figure 5.68
Year 6: Responses to vaccination and antibiotics



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

Interviews revealed a similar pattern of responses; six children indicated that antibiotics and vaccines were used as medication; some likened antibiotics to other familiar pain relief medication such as Calpol and Neurofen and the notion of a fight or conflict between the pathogen and the medication was evident in their responses:

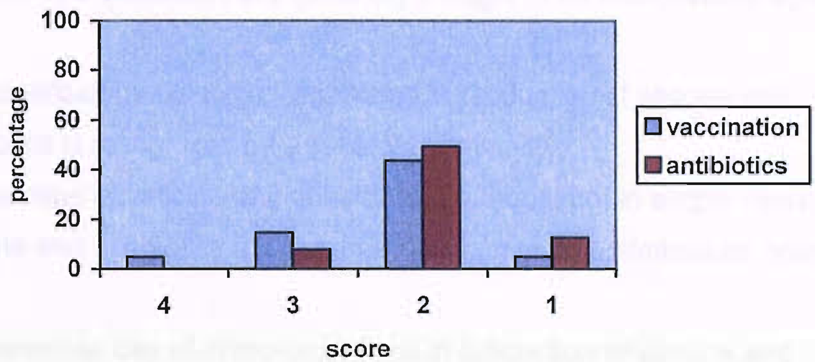
sm21	*I had medicine and injection and it just goes through and runs around your body.*
Interviewer	*What does it do when it's running through your body?*
sm21	*It's killing all the bad germs and everything.*

Four of the interviewees indicated that vaccine confers immunity and all responses infer the notion of a physical fight between the pathogen and the vaccine. However, one child indicated more sophisticated ideas about the immune response, *' I think they give you some sort of the actual disease and then the antibodies help fight it, but it's not very much, so they um, they make a special type of antibody. A special one that will, if I ever get the disease, then it will fight it, it will fight it immediately'* (sj53).

Year 9

Data from concept maps (Figure 5.69) suggest that the role of micro-organisms in the production of vaccine and antibiotics is not understood by the majority of children in this age group; 19.5 % and 7.8% stated that micro-organisms are used in the production of vaccine and antibiotics respectively, and 4.9% provided a slightly more sophisticated response with respect to vaccine, *'the injection gives the body germs so the body makes more stuff to get better so the body is immune to the next illness'* (ca89), although no further response was forthcoming about antibiotics.

Figure 5.69
Year 9: Responses to photographs of vaccination and antibiotics



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

The greatest response (score 2) to photographs of a vaccination (43.7%) and antibiotics (49.5%) indicates that about half this age group consider that antibiotics and vaccine combat microbial infection, or the disease that they cause, *'inject good germs so you can fight them'* (ca17); *'antibiotics contain micro-organisms to help kill off germs'* (ca5), and two interviewees likened antibiotics to common analgesics.

All interviewees knew that vaccine and antibiotics were used medically and 7 indicated that vaccine conferred immunity to the recipient, although only 3 stated that dead, or less pathogenic, micro-organisms were used in the vaccine:

ca100	*Yeah, it sort of like, makes your um, body immune to the disease.*
Interviewer	*Do you know how that works?*
ca100	*Isn't it something to do with, it sort of injects like a sort of, um, it's not as harmful of the disease, into your body, so it learns how to fight it, so if you get it again the body knows how to deal with it.*
Interviewer	*Do you know how your body knows that?*
ca100	*Yeah, is it that it produces the antibodies and then it knows how to fight them, kill the microbes of the disease.*

How micro-organisms are used in antibiotic production does not seem to be understood, although one child indicated at least some knowledge of the micro-organisms used in certain antibiotics, *'I mean, it could be used if it was a particular type of fungi, or bacteria for that matter, it could be used for um, ah, antibiotics and stuff'* (ca18). However, responses suggest that micro-organisms *per se* are actively engaged in a physical confrontation with pathogens.

5.8.4 Summaries progression and overview

A résumé of the findings about the medical applications of micro-organisms is presented below.

Year 2

- The beneficial use of micro-organisms in production of vaccine and antibiotics is not recognised;
- Vaccine and antibiotics are generally thought to be antimicrobial agents.

Year 6

- The beneficial use of micro-organisms in production of vaccine and antibiotics is recognised by a substantial minority;
- The function of vaccine and antibiotics are thought of in simple terms;
- Vaccine and antibiotics are generally thought to be antimicrobial agents.

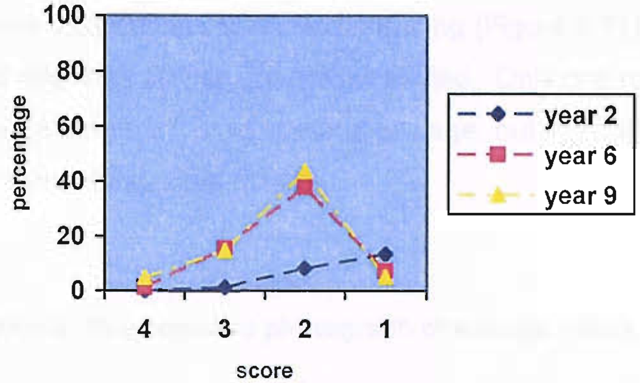
Year 9

- The beneficial use of micro-organisms in production of vaccine and antibiotics is recognised by a substantial minority;
- The function of vaccine and antibiotics are thought of in simple terms;
- Vaccine and antibiotics are generally thought to be antimicrobial agents.

Progression

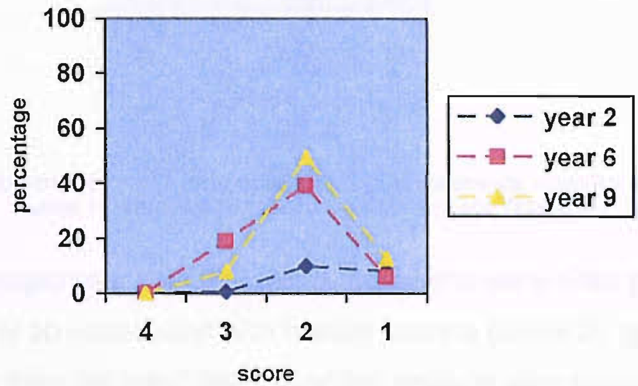
Figures 5.70 and 5.71 show the trend in children's ideas and indicate that progression about the use of micro-organisms develops between Year 2 and 6, but does continue between Year 6 and 9. The majority in all age groups focus on the use of antibiotics and vaccine as anti-microbial agents. In fact, it seems that fewer children in Year 9 are aware of the use of micro-organisms in Year 9 compared to Year 6. The level of alternative ideas also remains relatively stable across all age groups, indicating that some ideas are resistant to change.

Figure 5.70
Years 2, 6 and 9: Responses to photographs of vaccination



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.71
Years 2, 6 and 9: Responses to photographs of antibiotics



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Overview

The use of micro-organisms in the production of vaccine and antibiotics is not generally well understood by any age group and when this application is recognised it seems to be understood at a simple level; for example, micro-organisms being placed in vaccine or antibiotics as the active agent. Vaccine and antibiotics are more generally thought of as medication, which is not surprising as this is how the majority of children will have encountered them.

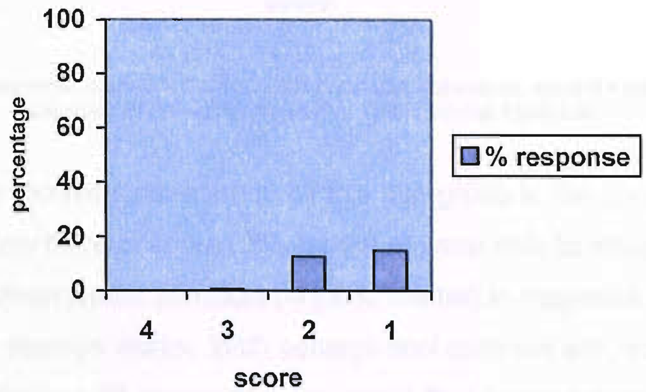
5.8.5 Environmental activity

Year 2

Positive environmental microbial activities are not generally recognised by this age group. The majority of children did not use the photograph of the sewage works, three interviewees did not know what sewage works were and no pictures, or brainstorms mentioned sewage works. The responses to the photograph of sewage works reveal different levels of understanding (Figure 5.72), although positive aspects of microbial activity are not presented. Only one response indicated that sewage works are used to clean sewage, but the comment does not indicate a positive view of microbial activity.

Figure 5.72

Year 2: Responses to photograph of sewage works



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

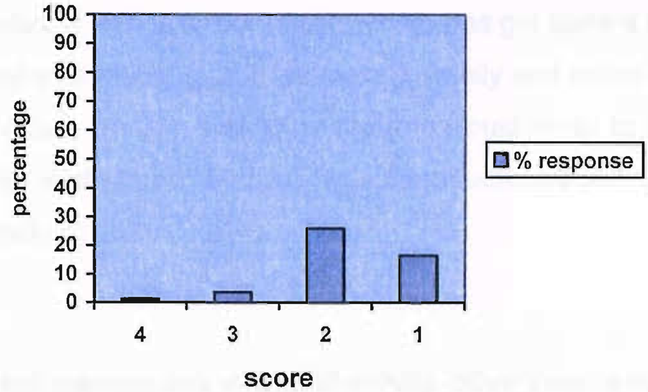
The commonest responses were that micro-organisms were often present in the sewage because of an association with human excreta (score 2), *'germs are here because it comes from the toilet'* (hai15), or that sewage works were dirty unpleasant dangerous places to be because there were so many micro-organisms there, *'a sewage works has germs because it has dirty water'* (si49); *'very very dangerous because there are a lot of germs'* (tb6), and therefore it presents a danger to human health, *'you need to wear a mask or you can die'* (hai31). Interviews also indicate that these ideas prevail:

tb2	*Yes 'cause sewage works are really filled up with germs 'cause you got lots of wee in it.*
Interviewer	*And what do they do there?*
tb2	*They go down under the sewer and if there's any one trying to sort out the sewer, it will affect them and they might die.*

Year 6

This age group did not mention any microbial activity, other than composting, as beneficial to the environment and this was considered at the simple level of enriching the soil.

Figure 5.73
Year 6: Responses to photograph of sewage works



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)

Figure 5.73 shows the responses made by this age group to the photograph of the sewage works. Only three children1.8% (score 4) were able to state that micro-organisms break down waste products (organic matter) in response to the photograph of the sewage works, *'both sewage and compost are broken down by microbes'* (sj4), a further 3% (score 3) were aware that harmful micro-organisms were removed from the water, *'they process waste with germs in'* (sj12). No interviewees were aware of the beneficial role of micro-organisms in purifying sewage.

Micro-organisms were associated with sewage works by 26.0% of the children (score 2), although their ideas were limited and many of the comments indicate a connection with human excreta, *'sewage is a prime place for germs as it is full of poo'* (sj47), and the sewage works seemed to be thought of as a depository rather than have any further function. Negative ideas about micro-organisms were also presented, *'it is full of gross waste which has lots of germs'* (sj28); *'carries billions of bad germs'* (haj12). This was a common explanation in interviews; the notion of micro-organisms increasing in number as a result of 'feeding' off the sewage and therefore posing a threat to human health was mentioned by four of those interviewed:

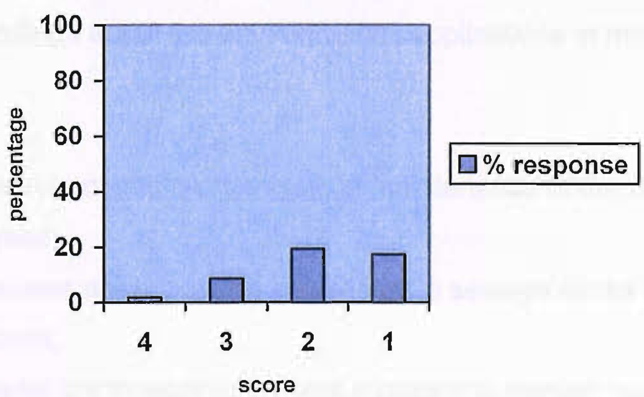
haj12	*Yes. I think a lot of bad fungi and viruses and stuff would be floating round inside and swimming round 'cause all of the horrible nutrients that's inside the sewage things. So I think there'd be a lot of bad bacteria and viruses inside that....... they'll be living off all the horrible stuff that's inside the sewage bits, whatever they're called, just living off all the bad, horrible, rotted, yucky stuff.*
Interviewer	*Is that a good thing or a bad thing?*
haj12	*A bad thing because they could spread in numbers and then through all the workers that work there could catch some kind of disease and then spread it round.*

Alternative ideas are suggested by 16.6% (score 1) of children and negative ideas about micro-organisms feature in many of the comments. Dirty and unhygienic conditions are associated with micro-organisms, 'this has got quite a lot of germs because it's dirty and everything' (sj30); 'sewage is smelly and micro-organisms come form smelly places' (sm33), and some children would seem to consider micro-organisms and waste to be identical, 'waste products are micro-organisms' (haj66); 'waste is made of germs' (sj14).

Year 9

This age group did not mention any microbial activity, other than composting, as beneficial to the environment and this was thought of simply as adding nutrients to the soil. Data from the sewage works probe indicate that little is understood about the role of micro-organisms in water purification. Figure 5.74 shows that this age group associates micro-organisms with sewage works, although only one child recognises that micro-organisms have a useful role, *'micro-organisms are used to purify raw sewage'* (ca53). Some children (8.7%) indicate that sewage works are useful environmentally because they help to purify the water of harmful micro-organisms, *'the sewage works filters the micro-organisms off the water'* (ca27); however this implies a negative perspective about micro organisms. The largest number, 19.4% (score 2) know that micro-organisms are present in the sewage works, often in large numbers and some make the connection with human excrement. A small number (6) thought that sewage works were dirty places and one child connected this to micro-organisms.

Figure 5.74
Year 9: Responses to photograph of sewage works



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement- see Table 4.6)

Similar findings were evident from responses during interviews; all nine children thought that micro-organisms were associated with sewage works, although only one response suggested that micro-organisms had a positive role, *'micro-organisms break down dirty things'* (ca41). Three children thought that micro-organisms were removed and the water is cleaned so that it is safe to be used, although the procedures were not explained or not understood:

ca18	*Um, yes but I'm not sure what. I would assume that um, there would be micro-organisms in the sewage works because that's why they're purifying the water, right, but ah…*
Interviewer	*When you say they're purifying the water…*
ca18	*No, they're [the micro-organisms]) not purifying the water, it, the water is there to be to purify the water of the micro-organisms.*
Interviewer	*Oh right, so, the sewage works purifies the water?*
ca18	*Yeah, and all the other stuff that's in it. Which we will not go into now!*
Interviewer	*Um… OK. So, do you know how that happens?*
ca18	*Um, they um, heat it and so it boils right, and um, then they basically send it through a tube and ah, it re-condenses at the other side, at least that's how you do it small scale, I'm not sure how you do it on a scale that large, but. That's a way you can purify water.*

Others thought that sewage works were beneficial because they stored the sewage, although that was considered potentially dangerous to humans because the number of micro-organisms would increase as they 'fed' on the sewage:

ca100	*Well it's sewage. Probably going to be germs and everything there, really.*
Interviewer	*And what are they there for?*
ca100	*They're not really there for anything, they're just sort of there because of the sewage.*
Interviewer	*OK. Do you think that's helpful or not, to have sewage works?*
ca100	*Nah, it's not really helpful. It's good for the germs, but not for us.*
Interviewer	*Why is it good for the germs?*
ca100	*Because there, they can live on sewage while they can continue to live and multiply.*
Interviewer	*Any why isn't it good for us?*
ca100	*Well, because we have to live with all the germs and things around us.*

5.8.6 Summaries, progression and overview

A résumé of the findings about the environmental applications of micro-organisms is presented below:

Year 2

- The positive role of micro-organisms in maintenance of the environment is not recognised;
- Micro-organisms are thought to be present in sewage works because of human excreta;
- Sewage works are thought to present a hazard to human health because of the presence of micro-organisms.

Year 6

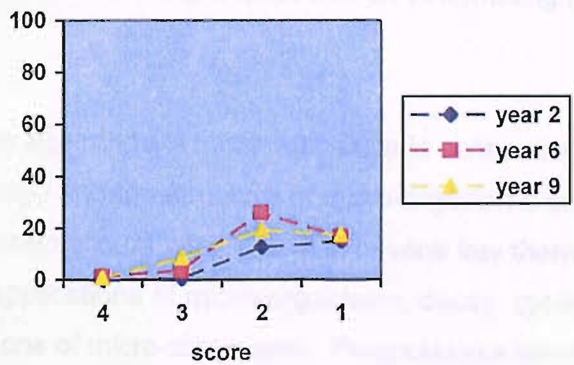
- o The positive role of micro-organisms in maintenance of the environment is not generally recognised;
- o A few children understand that micro-organisms have a role in the purification of sewage;
- o Micro-organisms are thought to be present in sewage works because of human excreta;
- o Sewage works are thought to present a hazard to human health because of the presence of micro-organisms.

Year 9

- o The positive role of micro-organisms in maintenance of the environment is not generally recognised;
- o A few children understand that micro-organisms have a role in the purification of sewage;
- o Micro-organisms are thought to be present in sewage works because of human excreta;
- o Sewage works are thought to present a hazard to human health because of the presence of micro-organisms.

Progression

Figure 5.75
Years 2, 6 and 9: Responses to photograph of sewage works



(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= non scientific / alternative statement-see Table 4.6)
Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 5.75 shows that very few children, in any age group, know about the role of micro-organisms in the purification of sewage and that little progression is made across the age groups. Alternative ideas about sewage works being hazardous to human health because of the presence of micro-organisms are retained by all age groups.

Overview

The low level of response seems to suggest that whilst children are able to comprehend the principles behind what happens in sewage works they are neither taught in school, nor know through their everyday experiences, about the function of micro-organisms in sewage works. The responses focus on negative aspects of sewage works as repositories for micro-organisms and, therefore, potentially dangerous to humans, indicating an anthropocentric perspective. The positive role of micro-organisms in the environment as a lynch pin in the cycling of matter is not understood by the majority of children. Simple ideas about composted materials providing nutrients in the soil, or the outcome of decay as a space saver, were typical of the few responses.

5.9 Summary

The findings presented in this chapter indicate that many ideas children hold about micro-organisms are broadly similar across the three age groups, for example, micro-organisms as the cause of disease. Negative ideas about micro-organisms prevail in all age groups, especially in connection with the threat they pose to human health. Anthropocentric ideas are also held by all age groups, although this aspect of children's thinking seems to reduce with age, ideas are retained by a substantial minority of Year 9 children. Responses from children in all age groups indicate the impact that first hand experience has on determining their ideas about micro-organisms.

Progression across the age range is most noticeable in connection with classification, morphology and the structure of micro-organisms as living things. However, little progression occurs after Year 6 in several key themes, notably, disease and medical applications of micro-organisms, decay, cycling of matter and technological applications of micro-organisms. Progression seems to be most pronounced between Year 2 and Year 6, although some of the youngest children hold advanced ideas that are congruent with those of older pupils.

The findings are discussed further in the following chapter and are used to present mental models of children's ideas about micro-organisms at different ages which more clearly illustrate the progression of those ideas.

Chapter 6

Discussion and conclusion

6.1 Introduction

The research presented here has attempted to discover children's ideas about micro-organisms across three age groups. The children in this study have followed the relevant programmes of study for science and all the Year 6 children had undertaken the short QCA unit of work on micro-organisms. The research questions set out below focussed the data collection and analysis of the findings; they are examined in this chapter and form the basis for the discussion that follows.

1. Can children's ideas about micro-organisms at different ages be identified, described and quantified?
2. Can changes in how micro-organisms are conceptualized at different ages be identified, described and quantified?
3. Can coherent mental models be constructed that are representative of children's ideas about micro-organisms?
4. Can a typology be developed to illustrate progression of children's ideas about micro-organisms?

This chapter discusses the key findings and presents generalised mental models of children's ideas about micro-organisms with regard to the key themes explored in this study. These models are used to aid the discussion of the findings of this study in relation to previous research. Further analysis of the findings enabled typologies, typical of the ideas held by each age group, to be developed. The typologies provide an indication of the level of progression of children's ideas about micro-organisms across the age groups investigated in this study. Progression of children's ideas and implications for learning, teaching and curriculum development, are discussed with respect to a constructivist approach to learning. Limitations of the research are explored, the findings in relation to the research questions are examined and the contribution this research has made to microbiological education and educational research is presented.

Recommendations for further work in this area of science education are also discussed.

6.1.1. Mental models and typologies

Findings show that the ideas that children hold about micro-organisms, with regard to each key theme specified in this study, vary in sophistication. The levels of sophistication have been characterised as, emergent, transitional and extended. The entire spectrum of these different levels of sophistication is represented in the ideas of each age group. Taking account of these findings, hierarchical mental models (Figure 6.1) have been developed that represent the ideas about micro-organisms held by all of the children in this study. The models, therefore, offer a generalised portrayal of the ideas held about micro-organisms for the age groups investigated. Further discussion of the models can be found in section 6.2. All three levels of sophistication are represented in the different age groups, but distribution differs. Three categories describe the degree to which each age group adheres to the different levels of sophistication for each model. The categories are:

- strongly held, the model that is held by most children;
- weakly held, the model that is held by the fewest children;
- moderately held, the model that is held by the rest of the children.

It has been possible to develop typologies (Figures 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7) that are representative of the ideas held by each age group, and that indicate progression of ideas across the age range studied. The typologies are discussed more fully in section 6.3.2.

The models represent the range of ideas about micro-organisms held within the age groups, the typologies indicate how the ranges in the models are distributed across the three age groups.

6.2 Children's mental models of micro-organisms

Mental models are an individual's images, personal ideas, or internal representations about a particular phenomenon, set of ideas, or concepts (Gilbert and Boulter, 1998). As such, they provide an indication of what ideas are held by individuals at a particular point in time (Greca and Moreira, 2000). In this study of children's ideas about micro-organisms, mental models can, therefore, help to clarify and define what the children know and understand about micro-organisms. However, as noted previously, mental models are considered as the personal ideas of individuals; they are therefore idiosyncratic. In attempting to form a model of what each age group in this study thinks about particular aspects of micro-organisms, it is acknowledge that any model offered is a generalisation, that any particular individual may hold a subtly different mental picture from those presented here, and that some ideas cannot be included within the generalised models. Nevertheless, the models presented here are formed on the basis of the empirical data analysed in Chapter 5 and illustrate the key ideas held by children in the three age groups. The findings and the summaries of children's ideas indicate that many of the key ideas are held in common by some children in all the age groups studied. One of the defining aspects of these ideas is their level of sophistication with respect to the generally accepted scientific ideas about micro-organisms discussed in Chapter 2. Accordingly, the different levels of ideas have been defined as emergent, transitional, and extended and three generalised models (Figure 6.1) for each key concept, explored in this study, have been developed. These models provide an indication of the level of understanding and the nature of knowledge about micro-organisms that all children in this study hold. The résumé that follows connects the findings of this project to previous research and provides illustrations of the models that have emerged from the data.

Figure 6.1: Generalised mental models of children's ideas about micro-organisms

Key theme	Emergent	Transitional	Extended
Classification			
o **Grouping**	non- biological entities, variation is based upon the level of virulence and the threat to human health	animal or animal-like, variation within groups is based upon appearance and activity which includes harm done to humans	single celled living organisms and distinct from plants and animals, variation within groups is generally based upon appearance and activity
o **Terminology**	single term used to one group generally referred to as germs	multiple terms used to refer to different groups which include micro-organisms, bacteria, germs and possibly fungi and viruses	multiple terms used to refer to different groups within the umbrella term 'micro-organism' these include bacteria, fungi, viruses, 'germ' is also a generic term
Morphology			
o **External appearance and features**	little animals, usually invertebrates and often anthropomorphised or human-like characters or abstract often geometric shape, anthropomorphic external features which may illustrate a harmful appearance	amorphous single 'cell' or recognisable plant or animal cell, may have external features e.g. hairs	single cells, some recognisable as bacterial cells, may have external features e.g. cilia/ flagella
o **Internal structure**	no internal structure	some indication of unnamed internal structure(s)	named cell organelles present,
Size and scale	Small, actual size not understood, size sometimes related to virulence	small / microscopic, size explained using everyday objects or specific vocabulary as a reference point	microscopic, requires magnification to be visible, size sometimes referred to in standard measures (but not necessarily understood)
Living and non living	non living	living, evidence-based on living processes especially movement and reproduction, as well as anthropocentric ideas, e.g. harm caused to humans	living, presence of cell structures/organelles included as evidence of living
Disease, heath and hygiene			
o **Disease and Infection**	all micro-organisms are potentially pathogenic and highly infectious, especially to humans, levels of virulence are not differentiated, illness is a spontaneous reaction to the presence of micro-organisms, contradictory ideas about modes of infection exist	not all micro-organisms are pathogenic, micro-organisms cause diseases, especially in humans, levels of virulence are not recognised, modes of infection focus on human transmission, contradictory ideas exist about modes of infection	not all diseases are caused by micro-organisms, some micro-organisms are pathogenic, the symptoms of illness are as a result of immune response to microbial activity, focus on human illness, levels of virulence may be recognised, various modes of infection are known although contradictory ideas still exist
o **Immunity, recovery and infection control**	immune response is not known, recovery is a spontaneous occurrence on the expulsion of micro-organisms, which may involve medication, simple hygiene precautions e.g. washing removes all micro-organisms and risk of infection	immune response involves a physical fight between the body and pathogens, recovery results from immune response and/or medication, special care , healthy diet, specific hygiene measures or using antimicrobial agents kills all micro-organism and risk of infection.	immune response involves a specific reaction to pathogens e.g. phagocytosis by white blood cells, antibody production, which eliminates micro-organisms, recovery from infection requires immune response and/or medication, hygiene precautions reduce the likelihood of infection by controlling microbial growth

Ecology ○ **location**	micro-organisms can be found in dirty, unhygienic places associated with animals, and as a result are a hazard to humans, micro-organisms exhibit free will and emotions about their location	micro-organisms can be found everywhere but especially noted for association with humans and are potentially harmful, micro-organisms exhibit free will and emotions about their location	micro-organisms can be found everywhere
○ **decay and cycling of matter**	decay is a result of age or physical conditions, decaying items (food, compost, sewage) are dangerous especially to humans and can cause illness because of the presence of micro-organisms, decaying items 'go bad' , change physically and may eventually disappear, all forms of decay are regarded negatively and positive role of micro-organisms in decomposition and cycling of matter not recognised	micro-organisms associated with decay items, cause decay by 'eating' items, decaying matter (food, compost or sewage) can pose a threat to human health because of the presence of micro-organisms, some forms of decay are regarded negatively, decaying items change physically and eventually disappear but some items are too hard to decay, the soil is the main end point for decaying items	decay requires a combination of environmental and physical factors for microbial growth, decaying item will change and eventually disappear, decay can be beneficial as a litter prevention mechanism or to provide nutrients in the soil
Technological applications ○ **food**	micro-organisms cannot be used to make food because they are dangerous (to humans)	micro-organisms are used to make certain food stuffs, yeast is the universal micro-organism used in the production of food	some microbial metabolic activities enable them to be used in the production of food stuffs
○ **medical**	vaccine and antibiotics are antimicrobial agents and kill pathogenic micro-organisms, cure (human)diseases caused by micro-organisms	micro-organisms are used in the manufacture of vaccine and antibiotics, vaccine and antibiotics contain 'good' micro-organisms to fight or kill 'bad' micro-organisms that cause (human)disease, vaccine can prevent further infections.	micro-organisms are used to produce vaccine and antibiotics, dead, attenuated, less pathogenic micro-organisms are used in vaccine to prevent diseases acquired immunity conferred as a result of vaccination, antibiotics not effective on viral infections
○ **environmental**	micro-organisms are dangerous to humans and are not beneficial to the environment, compost heaps and sewage works are dangerous because of the presence of micro-organisms and pose a threat to human health	micro-organisms can be useful to decompose matter to provide nutrients for the soil, compost and sewage is used by micro-organisms as a medium in which to grow and multiply and compost heaps and sewage works are therefore a potential source of danger to humans due to the large number of micro-organisms present	micro-organisms decompose organic matter and may help the environment as 'cleaners' e.g. in the purification of water and removal of organic 'litter'

6.2.1 Classification

Children in all the age groups in this study classify micro-organisms as single celled organisms, animals, or abstract entities. The latter two categories are resonant with the findings of previous researchers (e.g. Nagy, 1953; Vasquez, 1985; Simonneaux, 2000). Year 2 children, in particular, were found to consider micro-organisms as animals, whereas Year 6 and 9 children were less certain about micro-organisms actually being animals, but considered them to be animal-like, *'it looks like a cockroach'* (sm24). Although, some of the oldest children did show uncertainty about how to classify micro-organisms, *'Um, I think they're maybe animals...Cause they like, they're alive and they're not humans. They could be aliens, but I don't think so'* (ca78), and movement, or being alive were frequently given as reasons by all age groups for an association with animals; indicating a naïve perception of micro-organisms as living organisms.

Micro-organisms were also categorised as abstract non-biological entities, indicating that children are uncertain about what micro-organisms are. Like the findings of Nagy (1953), younger children tended to categorise micro-organisms as abstract entities. This age group referred to micro-organisms as things like pieces of dirt, *'germs are little bits of mud that get under your finger nail'* (hai34), similar to the findings of Kalish (1999) and Solomon and Cassimatis (1999). Nagy explains that very young children may have no concrete experience of micro-organisms hence their lack of understanding of them as biological organisms. It seems that the youngest children in this study have less understanding of micro-organisms as biological organisms compared to the two older age groups. As the understanding of biological concepts increases with age (Piaget, 1929; Carey, 1985) awareness of biological species, in particular animals, also develops (e.g. Braund, 1998; Tunnicliffe and Reiss, 1999). Although even more of the youngest children in this study classified micro-organisms as animals because this is likely to be the closest point of reference for them.

Older children in Maxted's (1984) and Simmoneaux's (2000) studies categorised micro-organisms as separate entities quite distinct from animals and often as 'things'. The findings of this study are encouraging, as they indicate that some understanding exists, in all age groups, that the micro-organisms represented here (bacteria, viruses, and fungi) do not belong to the more familiar taxonomic groups of plants or animals, but are different.

The idea that micro-organisms are different from other biological groups and that they are single-celled increased with age (Figure 5.13). It is possible that direct teaching about micro-organisms may have influenced children's ideas, although a small percentage of younger children drew cell-like micro-organisms, suggesting that some of the youngest children have an appreciation that micro-organisms are quite separate and distinct from plants and animals, even though they have had no formal teaching about this. More Year 9 children have more detailed ideas about cell structure, although their ideas are based on eukaryotic cells, which they will be more familiar with, rather than prokaryotic cells or viral structure and indicate a naïve view of microbial structure.

'Germ', was the universally used term by Year 2 children. Older children used a variety of terms; the way in which they were used indicates that what bacteria, viruses and fungi are and how they differ from one another is not clearly understood. 'Micro-organism', 'germ' and 'bacteria' were used generically by many children in a similar fashion to the findings of Maxted (1984). However, others used all the terms to represent different types. Awareness that 'micro-organism' and 'germ' are generic terms for all micro-organisms increases with age. Some children, in Years 6 and 9 also used the terms to denote one super-ordinate organism which resonates with the findings of Simonneaux (2000).

A further finding from this research suggests that variation between micro-organisms is thought, by children, to be based upon the effect they have on human health. The virulence of micro-organisms is a key discriminating factor for children in all age groups and whilst many older children refer to micro-organisms as, 'good', or, 'bad', the youngest children generally do not make this distinction.

It would seem that the classification of micro-organisms is difficult for children. This is not surprising, as taxonomists have disputed the exact classification for many years (Bisset, 1963; Woese *et al.*, 1990) and the reasons identified for these difficulties outlined in Chapter 2 seem to have been confirmed.

6.2.2 Morphology

The representations of micro-organisms produced by children in this study are similar to those of previous researchers; for example, Nagy (1953) and Vasquez (1985). This study has found that what children think micro-organisms look like changes with age, although all categories identified in this study were represented by some children in each age group (Figure 5.37).

Year 2 children are more likely to think of micro-organisms as looking like abstract entities, or small animals, and particular species such as, worms, caterpillars, or insects are commonly drawn and referred to. The 11-year-olds who consider micro-organisms to look like animals tended to refer to insects, whilst both worms and insects were represented in the few drawings of animals from Year 9. These children appear to have some ideas that micro-organisms are small living things and they have related them to animal species with which they are familiar. Year 2 and Year 6, in particular, seem to base their drawings on current or prior learning, representing micro-organisms as 'minibeasts', which they have studied as part of their science work in Key Stages 1 and 2.

Year 6 and 9 children, like the 14-15-year-olds in Vasquez's (1985)study, more commonly drew cell-like shapes, which suggests that older children do have some idea that a micro-organism is a unicellular organism rather than a complex multi-cellular organism. Although, it is possible that single representations are an artefact of the instructions, 'to draw ***a*** micro-organism', recognisable bacterial cells were present on some of both age groups' drawings, (24.7% of Year 6 and 16.9% of Year 9 drawings). Children appear to be more familiar with bacterial morphology, especially bacilli; compared to other micro-organisms, although it is surprising that more of the younger age group seem to have a better understanding of bacterial morphology. Lewis *et al.* (1997) noted in their study, that 48.1% of 15-16-year-olds regarded bacteria to be unicellular organisms, whilst the same percentage thought that viruses were multi-cellular. The findings in this study may be due to children's exposure to photographs, or drawings in school texts and reference books, or posters in doctors' surgeries, which tend to focus on bacteria.

Many of the drawings of micro-organisms as cells, especially those drawn by Year 9 children attributed the features of typical eukaryotic cells to their drawing, or were drawn as a specialised eukaryotic cell e.g. a sperm cell. Eukaryotic cell structure is studied at Key Stage 3 and, therefore, typical plant and animals cells form a key reference point for children in this age group. It appears that current learning about plant and animal cells, including diagrams in text books, has influenced this age group's ideas about the morphology of micro-organisms rather than any direct learning of microbial structure. Understanding about internal structure increased with age and this was also based on eukaryotic organisms. However, whilst structures were labelled, for example, 'nucleus', the structure and function, if mentioned, was referred to simplistically as having some kind of co-ordinating function, *'it's the ah, control centre for the cell. And then it literally tells , tells the cell what to do'* (ca54).

Younger children focused on external features, which tended to be highly anthropomorphic. All age groups indicated some evidence of anthropomorphism in their drawings and comments about the structure of micro-organisms. Although these ideas decreased with age (Figure 5.38), it is interesting to note that anthropomorphic views are retained by some (18.0 %), even in the oldest age group, which accords with the findings of Simonneaux (2000) in her study of 15-16-year-olds.

The notion that micro-organisms are thought to be harmful, or unpleasant was evident from drawings. Particular structures were drawn, most commonly in the Year 2 and 9 drawings; for example, monsters with sharp teeth, stings in tails, or associated with harmful animals, such as snakes, are reminiscent of the findings from studies by Nagy (1953) and Simmoneaux (2000). Representations of micro-organisms by Year 6 children tended not to indicate explicitly harmful structures, but they were associated with unpleasant conditions; for example, slime or spittle, indicating harm, especially to humans. The influence of television advertisements, cartoon programmes and other material, for example, health education pamphlets, which often depict micro-organisms as little animals, or monsters, seems to be evident in children's drawings (Figures 5.20, 5.25 and 5.30). The youngest and oldest children in this study provided the greatest number of examples of 'monster' drawings. The work Year 6 children had recently completed about micro-organisms may have provided them with more realistic ideas. Year 2 children had had no formal learning and therefore informal influences, such as cartoons, may well have a profound effect on their thinking. Year 9 children may have had greater exposure to images; for example, in health education materials, compared to the younger age groups and this may have had a significant influence on their ideas.

Drawings representing multiple entities were produced by all age groups and this may indicate that children know about microbial colonies, although as Nagy (1953) points out, there may be semantic reasons for this as 'germs', or micro-organisms', are generally referred to in the plural. However, the repetitive nature of many of the drawings in this study seems to indicate that children think micro-organisms are rarely found singly, especially as the instruction was to draw, 'a micro-organism'.

6.2.3 Size and scale

Micro-organisms appear to be thought of as very small by most children in all age groups, although reference to size increases with age (Figure 5.42). Like pupils in the previous studies, by Nagy (1953), Maxted (1984) and Simmoneaux (2000), there is a consensus view that micro-organisms cannot be seen with the naked eye. Reference to the need to be magnified before they become visible was an idea featured in responses from all age groups (Figures 5.39, 5.40 and 5.41).

However, the notion that micro-organisms are thought to be very small is not underpinned by children's understanding of actual size, or scale. Findings show that children in all age groups have very little idea about actual size. Everyday objects are used by the Year 2 and Year 6 children as comparators, for example, the end of a sharpened pencil, or a grain of rice, but the preferred means of explanation that Year 9 children gave, were terms such as, 'tiny'. Some attempts to use standard measures, for example, a millionth of a metre, were made by Year 6 and Year 9 children. These findings accord with previous research (Nagy, 1953; Maxted, 1984; Vasquez, 1985, Simonneaux, 2000) and indicate that, whilst there is a good understanding that micro-organisms are very small and the term *'microscopic'* is used widely, there is little appreciation of what this actually means with respect to the actual size of micro-organisms.

Whilst ideas about the relative size of different micro-organisms were confused, some children in all age groups associated virulence with size, suggesting that the bigger the micro-organism the more virulent it would be. This thinking was particularly evident with respect to viruses for 11 and 14-year-olds, *'and I've seen like, virus ....um, viruses are quite big because they can spread'* (haj77).

6.2.4 The living and non-living state

Findings indicate that all age groups consider micro-organisms to be living and evidence suggests that a combination of factors is used to justify why micro-organisms are considered to be alive (Osborne *et al.*, 1992). These include the 'seven processes' required for life, external features, and internal structure (Tables 5.19, 5.21.5.23 and Figure 5.43).

Like pupils in other studies (e.g. Vasquez, 1983; Maxted, 1884; Simonneaux, 2000) movement was commonly offered, as an indicator, by children in all age groups for considering micro-organisms to be alive, indicating that even the older children in this study retain these ideas. Reproduction was also referred to by all age groups, although multiplication was seen as an aggressive activity, in terms of the speed and rate of microbial increase and their subsequent proliferation, particularly by Year 6 children, with respect to the harm micro-organisms can cause humans. The notion of the speed of reproduction often seemed to be connected to ideas about the pervasive and dangerous nature of micro-organisms, indicating teleological reasoning on the part of these children. Others in this, and other, age groups suggest that being dangerous, or causing diseases to humans, was a sufficient reason for being alive and this is reminiscent of the findings of Nagy (1953), Maxted (1984) and Simonneaux (2000), indicating anthropocentric thinking on the part of these children. Year 2 and Year 6 also imbue micro-organisms with anthropomorphic characteristics such as emotions or free will, similar to the findings of Maxted (1984), but unlike Tamir *et al.* (1981) this type of thinking did not emerge in 14-year-olds' thinking.

Drawings were frequently anthropomorphised (Figures 5.17, 5.20, 5.23, 5.25, 5.28 and 5.30). External and anthropomorphic features were frequently given as reasons for micro-organisms being alive. Although anthropomorphic ideas did decrease with age, a substantial minority in Year 6 and 9 appear to retain these ideas which suggest that, even after several years of schooling, these children's ideas about life is distinctly anthropomorphic (Brumby, 1982).

The frequency of more sophisticated and extended reasoning, in terms of internal structure, about micro-organisms as living things increased with age. In particular, Year 9 children frequently drew and labelled cell structures; for example, a nucleus, cell membrane, and cytoplasm (Figure 5.33). The function of these structures was not employed as reasons for micro-organisms being alive (Lewis *et al.*, 1997). This age group, like those students in studies by Tamir *et al.* (1981) and Brumby (1982), readily reverted to older and possibly more stable knowledge in terms of living processes when articulating their reasons for micro-organisms being alive. It seems that many children in Year 9 had learned 'typical' cell structure and learned it very well, but were not sure of the metabolic processes associated with these structures and were, therefore, unable to apply their knowledge in unfamiliar contexts (Brumby, 1982).

A small minority of Year 2 children were not certain about whether they thought micro-organisms were alive. This seems to account for drawings of non-biological entities, such as abstract shapes, or pieces of dirt, similar to previous work (Nagy, 1953), and the lack of distinction, made by some in this age group, between micro-organisms and dirt (Kalish, 1999; Solomon and Cassimatis, 1999).

6.2.5 Disease, health and infection control

One of the key ideas that the children, in all age groups, in this study hold is the connection between micro-organisms and disease, *'germs are things that can get inside you and you get ill and poorly'* (hai72); *'micro-organisms can make you sick'* (sm5). This finding is no different from previous studies, for example, Nagy (1951), Maxted (1984); Prout (1985) and Springer and Ruckel (1992), who found a pathogenic view of micro-organisms was a dominant idea held by individuals of all ages, which Raichvarg (1995) referred to as 'microbe-mania'. However, some differences were noted between the youngest and the older two age groups. All Year 2 children seemed to consider that all micro-organisms are potentially pathogenic, highly infectious and dangerous, *'if a germ gets inside your body you shall be ill'* (si1). Year 6 and 9 children indicated a greater awareness that not all micro-organisms are pathogenic, which seems to accord with the views of Kalish (1999). Even so, findings similar to Nagy (1951); Bibace and Walsh (1980) and Hegenrather and Rabinowitz(1991), show that older children are not very aware of other causes of disease; only two Year 9 children mentioned genetic disease during the interviews. Other Year 6 and Year 9 children indicated confusion between microbial and non-microbial diseases, or attributed non-microbial disease to a microbial cause. It seems that the majority of children in this study have an exclusively exogenous notion of disease, in which a healthy individual is attacked by micro-organisms, and is in line with findings by Rumelhard (1986) and Simonneaux (2000). This has implications for children being able to comprehend the nature of genetic disease and, as Simonneaux points out, it raises questions about students' ability to understand and appreciate the ethical implications of such techniques as ante-natal screening. These considerations raise many sensitive issues with regard to genetic disease. Biotechnologies, using micro-organisms, that enable testing of those pre-disposed to certain genetic diseases, or other heritable characteristics which may be regarded as undesirable, do indeed pose serious ethical issues.

Nagy (1953) and Kiel (1992) suggest that young children do not distinguish between different micro-organisms as the cause of different diseases. This seems to be the case in this study. Although, unlike Maxted (1984) and Kiel (1992), who consider older children can discriminate between different microbial causes of disease, this study seems to indicate, generally, that no distinction is made. Very few specific pathogens were named and micro-organisms seem to be generically responsible for illness, *'lots are harmful and cause illnesses'* (sj17); *'infection, they can cause flu cold etc, mouldy bread, a nasty thing that goes into your body and destroys everything'* (ca76). Furthermore, as Simonneaux (2000) found, the children in all age groups in this study did not discriminate between the virulence of different micro-organisms, although different levels of severity of illness were remarked upon by all age groups. Like the findings of Nagy (1953) and Inagaki and Hatano (2002), these comments were made without reference to particular micro-organisms or the general health of the individual prior to infection. Some Year 6 children referred to the notion that large numbers of micro-organisms, or micro-organisms travelling through the body causes illness, whilst Year 9 children tended to refer to illness resulting from micro-organisms attacking the body. These ideas are also found in studies by Nagy (1953) and Simonneaux (2000).

Understanding how microbial infections are transmitted increases with age. Younger children tend to think that being in the presence of micro-organisms is sufficient to cause infection (e.g. Nagy, 1953; Springer and Ruckel, 1992), whilst a range of ideas are held by older children, such as coughing, sneezing, touching some one, or eating infected food stuffs will result in infection and ideas tend to focus on humans as the key vector (Vasquez, 1985; Simonneaux, 2000). Contradictory ideas about modes and causes of infection were found to be present in all age groups with regard to the common cold, similar to the findings of Maxted (1984); Prout (1985) and MacMenamy and Wiser (1997). All age groups in this study indicated that they held a germ theory of disease in conjunction with a non-germ theory, or that a biomedical model was abandoned in favour of a folk-lore model of disease when talking about common illnesses such as colds. It would seem that, as Helman (1978) says; the folk-lore model of infection is very persistent, in particular with regard to the common cold and the term 'cold' reinforces association with the environment. It would seem that children employ ontological ideas based on everyday experiences, for example, getting cold, to explain how they had a cold rather than through infection with a rhinovirus, the group of viruses responsible for the common cold.

This study has shown that differences occur between Year 2 and Year 6 children in the number who recognise a causal mechanism between micro-organisms and disease (Figure 5. 52). The youngest children in this study, like those in studies by Nagy (1953); Springer and Ruckel (1992) and Kalish (1996b), more readily attribute illness to the mere presence of micro-organisms, which spontaneously results in an individual becoming sick; whilst more Year 6 and Year 9 children consider that micro-organisms cause disease by being the active agent attacking the body. However, few children in any age group had more sophisticated ideas about the aetiology of disease, or that the symptoms of disease are the result of an immune response to infection; for example, responses to photographs of the sick child and of vaccine (see sections 5.6.1 and 5.6.3). However it is interesting to note that a similar small proportion in all age groups held these more sophisticated ideas, similar to the findings of Au *et al.* (1999), in their study with children between 5 and 13 years.

Similar to the findings of other studies; for example, immune response to either infection or vaccination is not generally understood by any children in this study (Figure 5.70). Awareness of some kind of bodily response involving a fight, or pitched battle with pathogenic micro-organisms, is represented in all age groups and is similar to responses noted by Vasquez (1985), Rumelhard (1986) and Simonneaux (2000). By Year 9, terms associated with immune responses such as, 'antibodies', 'cells', and 'white blood cells' are used. However ideas, generally, seem to be confused about what occurs at the cellular level and explanations of acquired immunity remain relatively simplistic.

Aligning with the findings of Nagy (1953) and Barenholz and Tamir (1987), all age groups in this study consider that recovery from infection occurs automatically on the removal of micro-organisms from the body, although some Year 9 children thought that recovery occurred naturally over time, but further explanations of an immune response were not forthcoming. Year 2 and Year 6 children consider that some kind of physical activity, such as, blowing your nose, or being sick, will remove the micro-organisms. Year 9 children tend to focus on medication as a means of removing, or killing micro-organisms that are causing disease. In addition, some Year 6 children thought that physical conditions, such as staying warm, special care, or a healthy diet, would enable recovery from illness, although ideas about how these might effect the immune response was not clarified.

Studies by Maxted (1984), Prout (1985) and Simonneaux (2000) have shown that the effect of medication in the cure and prevention of disease is not well understood. This study indicates that all age groups consider all medication to be simply anti-microbial agents and no difference is noted between curative and relief medication. In fact, antibiotics, vaccine and patented medicines such as 'Calpol' or 'Neurofen' are regarded, by some children, as having the same effect as each other. This response to having antibiotics, 'Yes *like Ibuprofen and stuff, for headaches, I've had that'* (ca62), illustrates the point. The notion of a pitched battle in which all medication, including antibiotics and vaccine, contain 'good' micro-organisms as the active agents to fight pathogens, is commonly held by all age groups.

Children's ideas about infection control are like those of Simonneaux (2000). Simplistic notions that hygiene precautions remove all micro-organisms seem to exist across all age groups, even though this seems to be inconsistent with the notion, especially from Year 2 children, that micro-organisms are highly infectious and dangerous. Brainstorm comments revealed Year 2 children's tendency to focus on washing to remove micro-organisms, whilst Year 6 included references to specific hygiene measures, such as refrigerating food and Year 9 referred to cleaning food surfaces. It may be that informal learning, for example, being told at home to wash hands after going to the toilet and formal learning in home economics lessons has influenced these children's ideas.

Bleach is regarded as an antimicrobial agent by 45.6% of Year 6 and 44.7% of Year 9 children. There seems to be an assumption that the removal of micro-organisms is absolute and permanent. It is possible that advertisements on television may have influenced these ideas. Bleach is also is likened to antibiotics and vaccine, by some children, as an antimicrobial agent and some Year 6 children consider that it contains 'good' micro-organisms to remove 'bad' ones.

Anthropocentric thinking prevails in all age groups with regard to micro-organisms as the cause of human illness and human illnesses were the only examples given by all age groups (see section 5.6.1). Anthropocentric explanations were also offered with regard to the immune response, and recovery from infection; for example, the notion of the body talking to the invading pathogen and the idea that human intervention, through special care or diet, alone can expedite recovery from infection (see section 5.6.4).

6.2.6 Ecology and ecosystems

Previous studies, e.g. Maxted (1984); Vasquez (1985) indicate that the ubiquity of micro-organisms is generally understood by children, and children in this study indicated that micro-organisms could be found in a variety of locations (Figure 5.53). However, unlike Nagy (1951), who found that young children had a restricted idea about where micro-organisms could be found, it is the oldest children in this study that seem to have a more restricted notion, that focuses on human beings, as the principal point of microbial location. Connections with humans seems to increase rather than decrease with age and this may be due to the curriculum that focuses on micro-organisms as agents of (human) disease in early secondary school. The ubiquity of micro-organisms seems to be a more predominant idea of the Year 6 children, *'you might, you could find them anywhere across the world. Could be the cleanest place on the planet and you could still find bacteria there'* (sm17), and this seems to be in direct contradiction to another notion that this age group holds of micro-organisms, requiring specific conditions in order to survive. The specific teaching sequences that this age group receives may provide them with a confusing picture, because the micro-organisms that are generally exemplified, are those associated with humans.

Association with unpleasant and dirty conditions is a frequently held idea (Nagy, 1953; Maxted, 1984; Simonneaux, 2000); all age groups in this study referred to dirty places, rubbish, dustbins, the soil, as places where micro-organisms can be found. Compost heaps and sewage works were also regarded by many children, in this study, as dirty and unhygienic and they assumed that micro-organisms would, therefore, be found there in large numbers, although this view did decrease with age. Like previous studies, the link between dirty, unhygienic places and micro-organisms and the threat they pose to human health are well established ideas and indicate an anthropocentric perspective about microbial habitats. Further anthropocentric thinking is evident as children in Year 2 and 6 ascribe free will and emotions to micro-organisms about their location, for example, suggesting that micro-organisms can make rational choices about where they live.

Leach *et al.* (1996) noted that children aged between 5-16 years did not readily cite micro-organisms as the agents of decay and findings in this study are similar. Recognising micro-organisms as the agents of decay does improve with age (Figures 5.57, 5.58 and 5.59). The role of micro-organisms in the decay process was not generally well understood by any age group in this study. Responses such as micro-organisms rotting, decaying, or breaking down things were common and further explanations, such as micro-organisms feeding, eating or taking over the item are similar to those found by Sequeira and Freitas (1986), Leach *et al.* (1996) and Hellden (1996). The ideas are simplistic and anthropomorphic. Even the oldest children do not understand the metabolic activities that enable micro-organisms to use organic matter as a substrate in which to grow and multiply. Other causes of decay, such as age, or environmental factors were cited by all age groups and the notion of items decaying naturally as a consequence was present in all age groups, reminiscent of findings by Smith and Anderson (1986) and Leach *et al.* (1996). Although, some Year 6 and Year 9 children did consider that decay was the result of a combination of factors, which differs from the findings of Leach *et al.* (1996), but the complexity of the inter-relationship between physical factors and conditions for microbial growth was not generally understood.

Everyday experiences of food decay seem to give rise to ontological reasoning about the fate of decaying matter and indicate a lack of understanding about the conservation of matter. All age groups in this study suggested that the effects of decay on food items results in them changing physically, getting smaller and eventually disappearing and are similar to the findings of previous work; for example, Hellden (1996). Although some children in this study considered that certain items; for example, the peach stone, was too hard to decay and would remain. The idea that matter would disappear was regarded as a beneficial outcome of decay, especially by Year 6 children, as this would stop the world from becoming filled with dead plants and animals. Organic matter that was placed on a compost heap was thought to break down and produce compost or soil and some Year 6 and 9 children thought that the resulting soil would be enriched and contain nutrients for plants. The notion that the soil is an end point in the decay process rather than an essential phase in the cycling of matter has been noted previously, for example, in studies by Smith and Anderson (1986) and Hellden (1996). In addition, the role of micro-organisms in the decay process was not clearly understood by children in this study and many children, in all age groups, thought that decay would occur 'naturally' over time or was a factor of age.

Findings from this study also suggest that children do not have a clear understanding of the essential role of micro-organisms in the maintenance of ecological balance. Their role in decay, where it is acknowledged, seems to end with initial decomposition to provide nutrients to the soil, or in litter prevention. Knowledge of microbial activity in the conversion of organic matter to inorganic and the reverse is not recognised. Lin and Hu (2003) noted that the 13-year-olds in their study had a weak knowledge of the interconnectedness of biological processes although, promisingly, Hogan and Fisherkeller (1996) found that children who assimilated new knowledge about micro-organisms as agents of decomposition could use this knowledge to develop ideas about nutrient recycling.

Negative aspects of decay, for example, food spoilage resulting in food being inedible, are mentioned by all age groups. Year 2 and Year 6 children also clearly related this to potential ill health. Micro-organisms are highly associated with decaying food, by these age groups, because it is regarded as potentially dangerous and poses a threat to human health, but unlike the findings of Simonneaux (2000), older children did not refer to food spoilage as a potential health hazard. Year 9 children, generally, thought positively about compost heaps as places where organic matter could be broken down to provide nutrients for the soil, whereas the younger age groups thought of them as a threat to humans because of the presence of micro-organisms. Year 2, and to a lesser extent Year 6, children have anthropocentric ideas about the danger all decaying matter poses to human health, as a result of contamination by micro-organisms.

6.2.7 Technological applications

Previous research shows that the use of micro-organisms by humans to manufacture food (Williams and Gillen, 1991; Simonneaux, 2000), for medical products (Maxted, 1984; Simonneaux, 2000), or for environmental benefit is poorly understood. The findings from this study indicate that, whereas responses to the uses of micro-organisms by humans was generally low, food production is more commonly recognised as a microbial application compared to either medical or environmental uses and acknowledgement of their use increases with age (Figures 5.63, 5.64 and 5.65). However, the metabolic processes involved in production of bread, beer and yogurt were not generally understood, and is similar to the findings of Simonneaux (2000). Yogurt was associated with sour milk, or allowing the milk to 'go off' by some Year 9 children indicating a lack of awareness of the role of micro-organisms in yogurt production. The use of different types of micro-organisms in food production was not generally recognised. Yeast seems to be considered as a 'universal' micro-organism used in food production, which is probably due to limited experience of science practical work together with the influence of food technology lessons.

Micro-organisms were connected with food as potential contaminants by all age groups, especially Year 2 (Figure 5.66) and some comments, '*Um, because if germs actually made that food, when you have it, it will make you ill*' (si9), indicate that micro-organisms could not be used for food because of their negative connotations. Anthropocentric ideas prevail in Year 2 and Year 6 about the danger micro-organisms pose to human health in relation to food.

The use of micro-organisms in vaccine and antibiotic production was not generally recognised, but some Year 6 and 9 children seemed to be more aware of their use than Year 2 (Figures 5.70 and 5.71). However, their function was frequently explained in simple terms, as 'good' micro-organisms being the active agent in both vaccines and antibiotics. The specificity of vaccines or antibiotics was not explored and more complex ideas, such as killed, or attenuated micro-organisms, or less virulent species used in vaccines were mentioned by only a small minority of children, similar to the findings of Maxted (1984) and Simonneaux (2000). It is interesting to note that although this explanation seemed to increase with age the sophistication of the explanation did not increase similarly. The majority of responses from every age group, like the findings of Simonneaux (2000), indicate that vaccines and antibiotics are primarily regarded as anti-microbial agents and often equated to be the same. Leach *et al.* (1996) and Simonneaux (2000) noted that the positive role of micro-organisms in benefiting the environment was poorly understood; little was understood about sewage works and composting was mentioned by only a few children. Children in this study hold similar views: Year 2 children did not recognise microbial activity in either composting, or sewage works; rather they believed that they were dangerous, unhygienic places because the presence of micro-organisms would cause harm to humans. Composting was the only environmentally positive microbial activity cited by any child in Year 6 and 9. Sewage works were generally thought of as places where dangerous micro-organisms were removed from the water and because of their presence often thought to be in large numbers, sewage works presented a threat to human health.

6.2.8 Other issues

Considering what children know and understand about micro-organisms in relation to the key themes presented and explored in this study, two ideas are threaded throughout children's responses; these are anthropocentric notions when thinking about micro-organisms and a negative attitude towards micro-organisms. These views were present in responses from every age group and appeared within the data across the range of research methods used. Whilst neither of these views sits exclusively alongside a scientific conceptual theme, they are nevertheless important aspects of children's ideas about micro-organisms and inevitably have consequences for learning this aspect of science.

a. Anthropocentric views

Anthropocentric ideas about micro-organisms are apparent in the responses from all age groups across many of the key themes, for example morphology, location, disease and health, as well as the microbial applications considered in this study. Although anthropocentric ideas are not inherently a problem for children's learning, and may help children understand and explain ideas; the imbalance in children's ideas appears to prohibit children considering other aspects of micro-organisms; for example, the importance of their role in decomposition and cycling of matter, or their beneficial technological applications. Furthermore, the focus on humans and the danger micro-organisms are thought to pose to their health creates a hostile view of micro-organisms. Although anthropocentric ideas reduce with age they are retained by many older children and this not only affects their ideas, but may affect later learning.

b. Negative views

Findings indicate that children hold some negative ideas about micro-organisms. Whilst an almost universally negative view is held by Year 2 children, negative aspects of microbial activity predominate in many children's ideas in Year 6 and Year 9. The risk that micro-organisms pose to human health is apparent in such diverse conceptual themes as classification, morphology, disease and health, locations, decay and technological applications of microbial activity. Micro-organisms are associated with dirty and unpleasant conditions and some Year 2 children consider that dirt and micro-organisms are the same thing. The reproductive properties of micro-organisms are regarded as a potential hazard, as they are thought to invade humans, or items, such as bread where they breed in large quantities and therefore become an even greater threat to humans. Medication and bleach are regarded in a positive light, by the majority of children in all age groups, as anti-microbial agents to kill the micro-organisms or remove the danger they pose. Negative ideas seem to predominate many children's responses in all age groups. Even though more positive aspects of micro-organisms are recognised by Year 6 and 9 children, negative ideas remain and seem to obscure a more holistic view of micro-organisms and their activities. It seems, despite a broader understanding about micro-organisms, older and more strongly held ideas remain whilst newer ideas are more readily rejected.

6.2.9 Summary of discussion of findings and previous research

The résumé of the findings in relation to previous research indicates what children think about micro-organisms in different contexts, different countries, at different ages and at different points in time are remarkably similar and the models identified from this work could be applied to others' findings. The similarity of ideas across the age groups and between different studies is quite surprising for several reasons; firstly the Year 6 and Year 9 children in this study will have been formally taught about micro-organisms. It might be expected that more differences from Year 2, who were not formally taught, would be apparent. Secondly, more differences might have been expected due to the cognitive development across the age ranges studied. Thirdly, some of the studies (Nagy, 1953; Maxted, 1984) were carried out in the U.K. before the National Curriculum for Science when formal teaching about micro-organisms was unlikely. Finally, the learning experiences of the pupils in different countries are likely to be quite different. However, in general the findings do seem to indicate that perceptions and understanding about particular aspects of micro-organisms are universally held and that these transcend time, place and age.

6.3 Key findings of the study

The key findings are discussed with the research questions in mind and consider, in particular, children's learning about micro-organisms at different ages and the progression of their ideas with age. The mental models described earlier (Figure 6.1) offer opportunities to develop insights into children's knowledge frameworks concerning micro-organisms. The ideas children have at different ages and the progression that occurs between the age groups are dealt with from a constructivist epistemological perspective.

6.3.1 Children's learning about micro-organisms

a. Learning

One of the tenets of a constructivist view of learning is that children do not come to a learning situation with an 'empty head' and that everyday experiences influence children's learning (e.g. Driver, 1989; von Glasersfeld, 1989). The models clearly illustrate that children in all age groups have a wide range of ideas embracing the key concepts explored in this study. Furthermore, the ideas that children hold are not necessarily in line with accepted scientific thinking. It is clear from the models that have emerged that children in all age groups hold ideas that depart from the scientifically accepted view of micro-organisms. It is also worth noting, that even the extended model that has emerged, falls short in many respects of the scientific view of micro-organisms and what children at the end of Key Stage 3 might be expected to know and understand as a result of learning and teaching about micro-organisms. This has implications for children's future progress in learning about micro-organisms, as particular concepts may appear unrelated to their own mental models; the gap between what the children think and what is being taught may be too great so that they are unable to resolve their confusion. In these circumstances, children may prefer to retain their previously held ideas, making conceptual change less likely because of the lack of cognitive dissonance (Driver, 1993), or dissatisfaction with their own model (Strike and Posner, 1982).

The fact that some children in all age groups have emergent mental models about particular aspects of micro-organisms suggests that some knowledge is entrenched and highly stable. Their alternative ideas are difficult to change and are retained despite formal learning, and these ideas are used to explain concepts which indicate ontological reasoning on the part of these children (Simonneaux, 2000).

b. Learning contexts

Findings suggest that learning about micro-organisms appears to occur in a range of contexts, which includes home and school. Common life experiences, for example, being taught to wash hands after visiting the lavatory, television advertisements and media portrayals of micro-organisms, or being ill have all influenced children's ideas. Strong emotional connotations about micro-organisms are evident in the data and the influences of the experiences just described are likely to have made a contribution to children's views, suggesting that children's ideas are to some extent socially mediated.

Findings also suggest that children divorce science taught in school from everyday ideas, for example, ideas about what causes the common cold. Compartmentalising learning within specific contexts enables different ideas to be held contemporaneously and avoids dissonance (Driver, 1989; Whitelock, 1991). In these circumstances conceptual change is less likely to occur (Driver, 1993). As Novak (2002) indicates, meaningful learning will only take place when there is reciprocal transfer between ideas derived from different contexts, which enables children to make use of ideas derived from the science learnt in the classroom to solve everyday problems.

6.3.2 Progression of ideas about micro-organisms

The findings of this study show the predominance of certain models within each key conceptual area differs between age groups, indicating that the way micro-organisms are conceptualised is different for all age groups. Each model has been ascribed a weighting representing strongly, moderately or weakly held ideas by each age group, based on an amalgamation of the findings for each age group (see Appendix 7). In addition, the extent to which children in different age groups have anthropocentric ideas and negative views about micro-organisms is included in the discussion about the progression of children's ideas that follows. Identifying these differences between age groups has enabled the models to be placed in hierarchical typologies, typical for each age group; (Figures 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7), which provide an overall indication of progression in ideas between the age groups.

Hierarchies can be dangerous, as it might be expected that children will travel from one level after another in a sequential manner and that learning is, therefore, a linear progression. Learning is not generally considered to be so simplistic (e.g. Carey, 1985; di Sessa, 1988; Driver, 1993; Harlen, 2000). The findings discussed in Chapter 5 and the hierarchical typologies produced for each age group indicate that learning about micro-organisms is no different from other aspects of science in that linear progression is not evident; learning does not seem to be straightforward, or a matter of one, or two, formal learning sequences.

Figure 6.2
Year 2: Typology of ideas about micro-organisms: classification, morphology, size and scale, living or non-living
Key
Emergent: Transitional: Extended

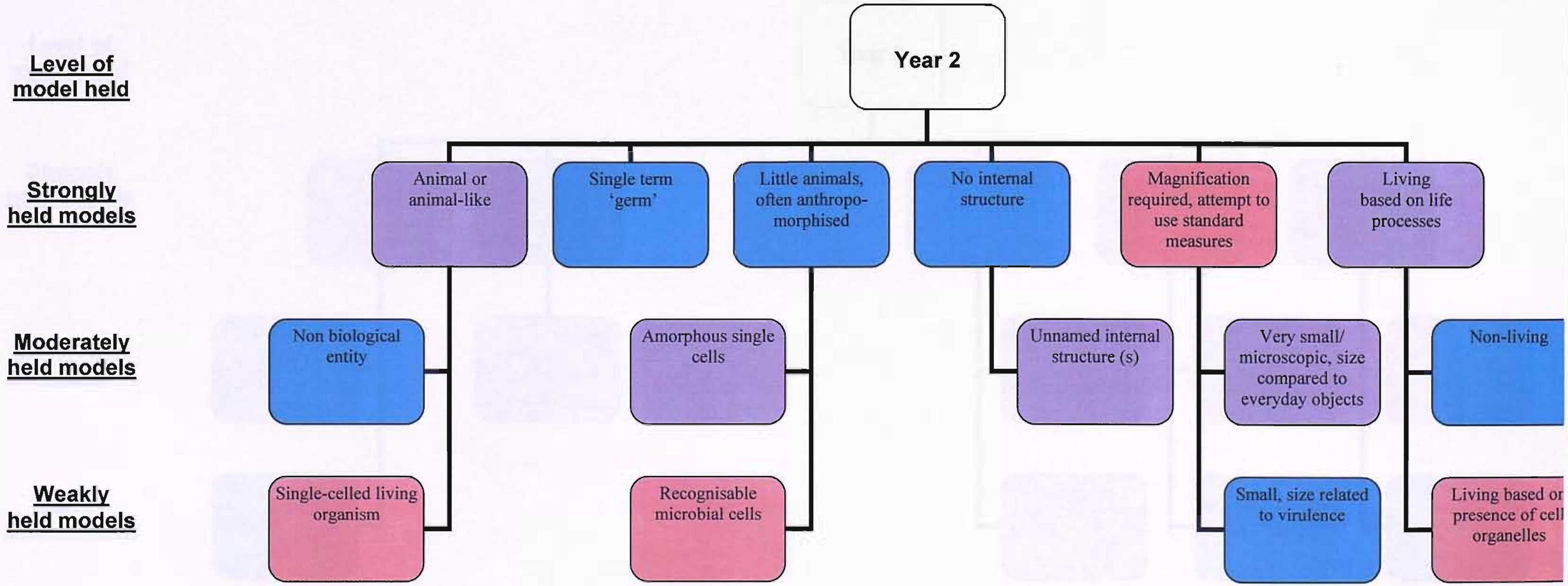


Figure 6.3
Year 6: Typology of ideas about micro-organisms: classification, morphology, size and scale, living or non-living
Key
Emergent: Transitional: Extended

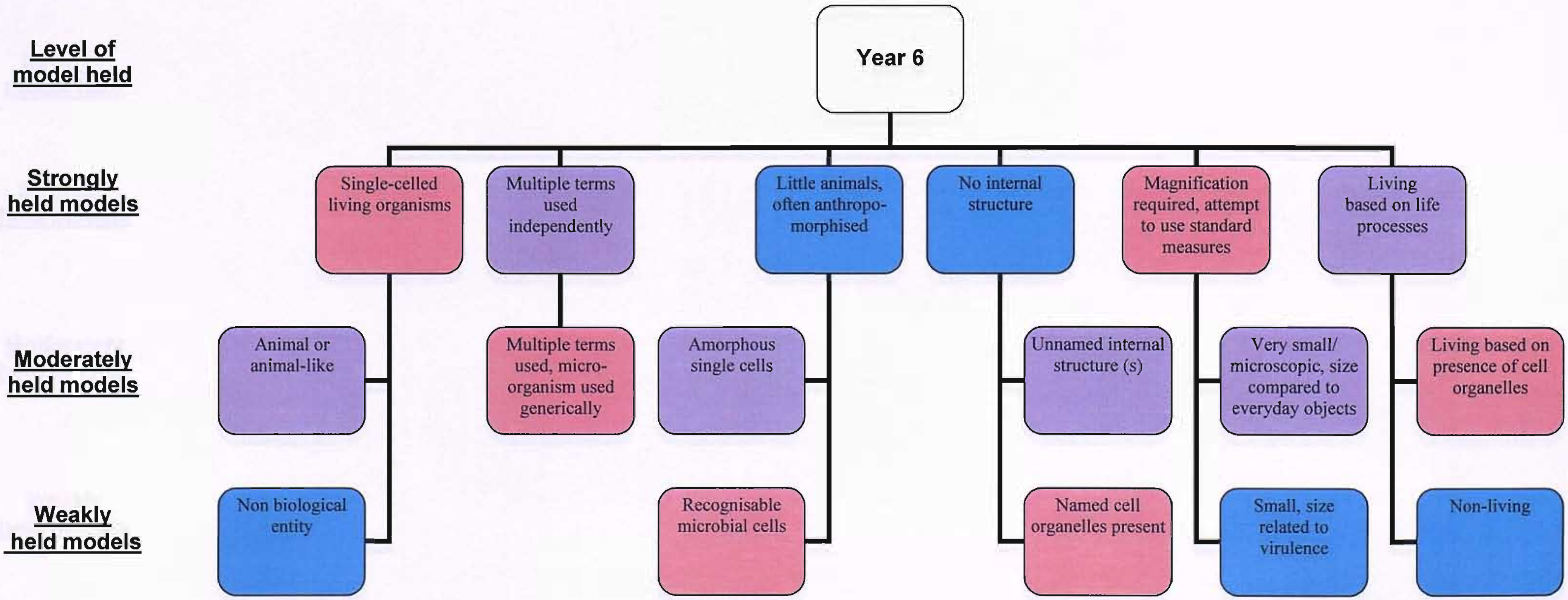


Figure 6.4
Year 9: Typology of ideas about micro-organisms: classification, morphology, size and scale, living or non-living
Key
Emergent: Transitional: Extended

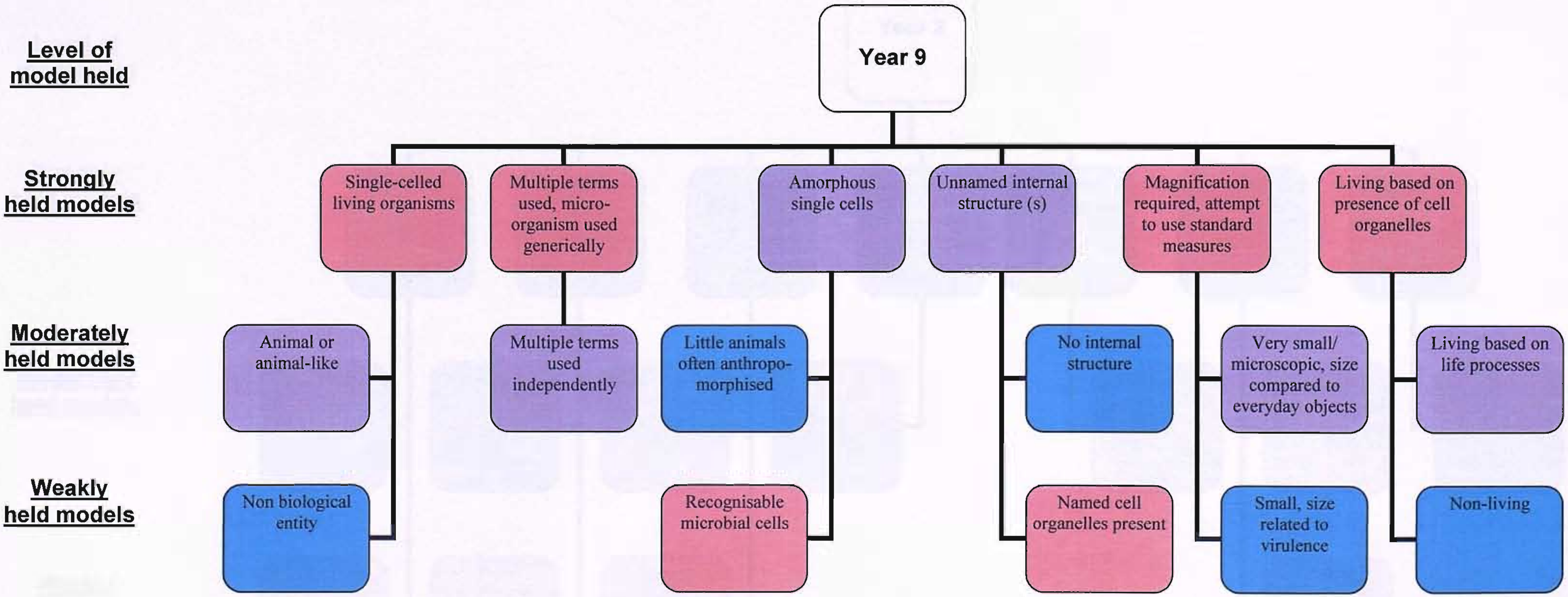


Figure 6.5
Year 2: Typology of ideas about micro-organisms: disease, health and infection control, ecology and ecosystems, technological applications
Key
Emergent: Transitional: Extended

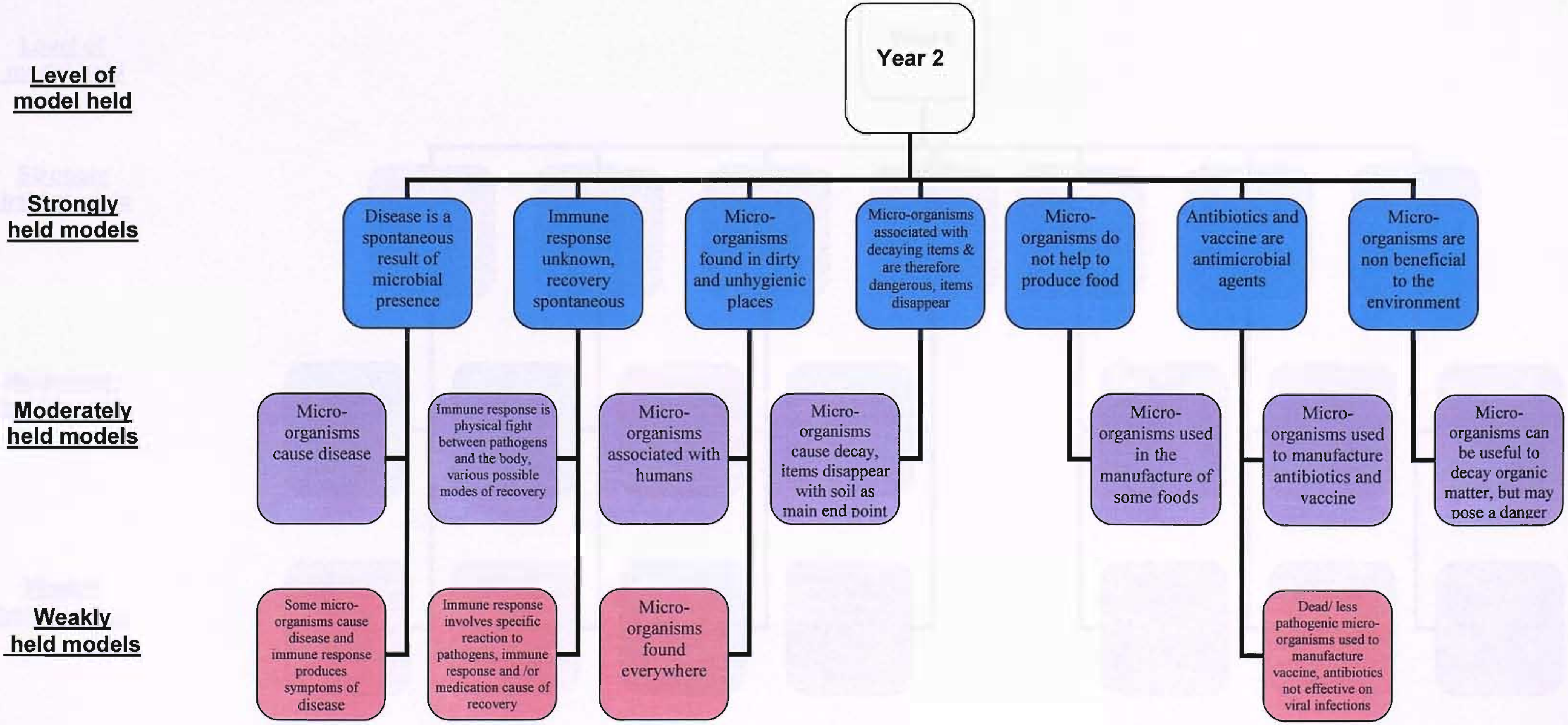


Figure 6.6

Year 6: Typology of ideas about micro-organisms: disease, health and infection control, ecology and ecosystems, technological applications

Key

Emergent: Transitional: Extended

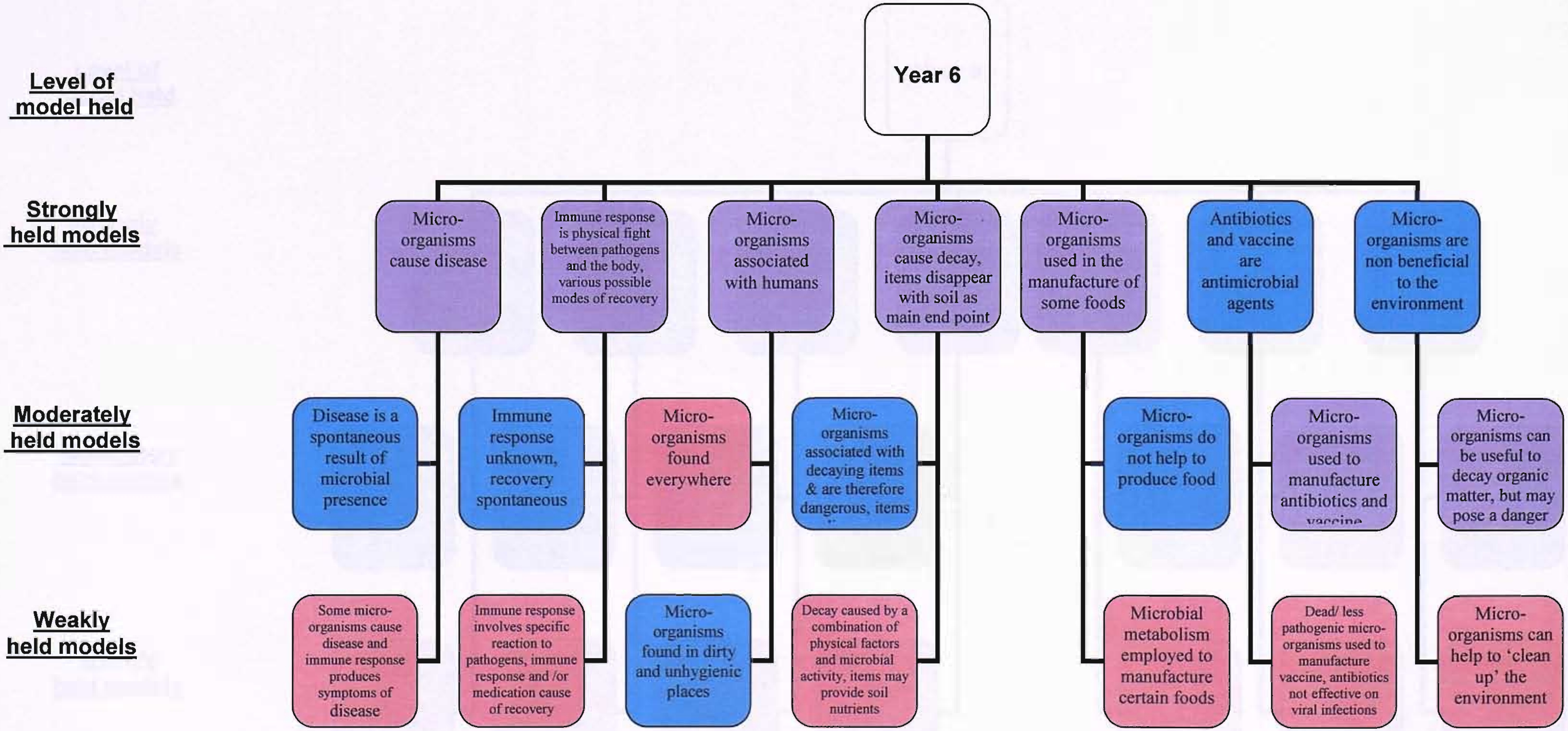
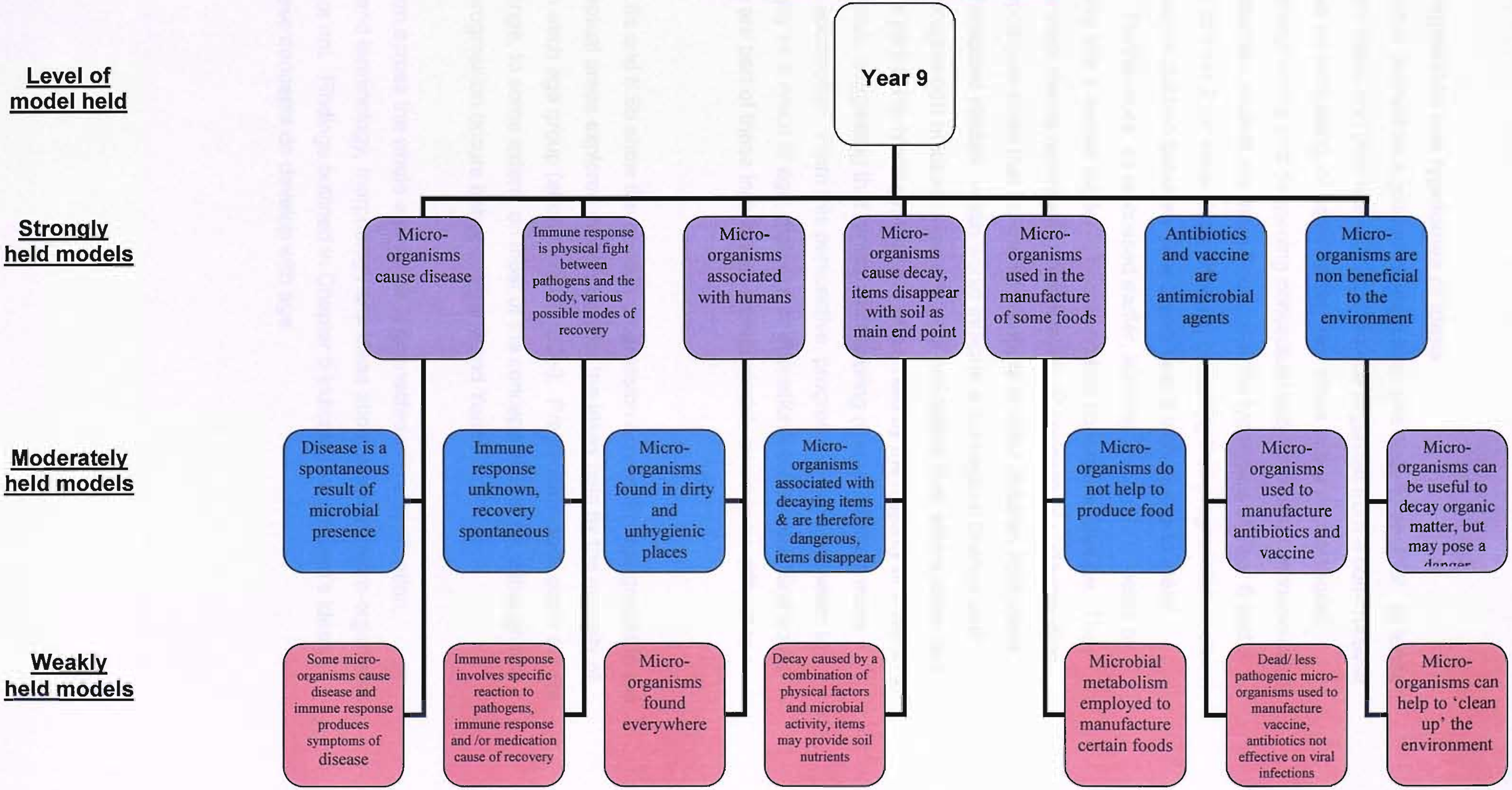


Figure 6.7
Year 9: Typology of ideas about micro-organisms: disease, health and infection control, ecology and ecosystems, technological applications
Key
Emergent: Transitional: Extended



a. Progression and typologies of ideas

Progression is defined as a gradual change from one state to another. In terms of children's ideas and their learning, this may be regarded from a constructivist perspective as increasing, or assimilating, new ideas into a mental model, thereby strengthening and deepening conceptual understanding (Johnson-Laird, 1983). Extended models are more frequent in the typologies of Year 6 and 9 compared to Year 2 for several key themes, indicating that progression does occur for some children between Year 2 and Year 6 with regard to these concepts. Furthermore, as discussed earlier, learning is thought to occur by restructuring one's mental model to accommodate conceptual change. The models for each theme represent different levels of conceptual understanding and the typologies show that increased numbers of older children hold these more sophisticated models, which would indicate a conceptual change and therefore progression of ideas. However, it is noticeable that, where extended models are part of the typology, they are rarely held by the majority of children in any age group, suggesting that radical restructuring (Carey, 1985) is more difficult to accomplish. From this perspective, progression does not seem to occur simply as a result of age, maturity, or educational experience, and some ideas that are part of these individuals' mental models seem to be difficult to change.

Figures 6.8a and 6.8b show the trend in progression across the age groups in the key conceptual areas explored in this study for the ideas held by the majority of children in each age group (strongly held model). Progression does occur across the age range, to some extent, on most of the conceptual themes, although the greatest progression occurs between Year 2 and Year 6.

Progression across the whole age range is connected with classification, grouping and terminology, morphology and ideas about whether micro-organisms are living or not. Findings outlined in Chapter 5 indicate that children's ideas across these concepts do develop with age.

Figure 6.8a

Years 2, 6 and 9: Strongly held models (models held by the majority of children in each group)

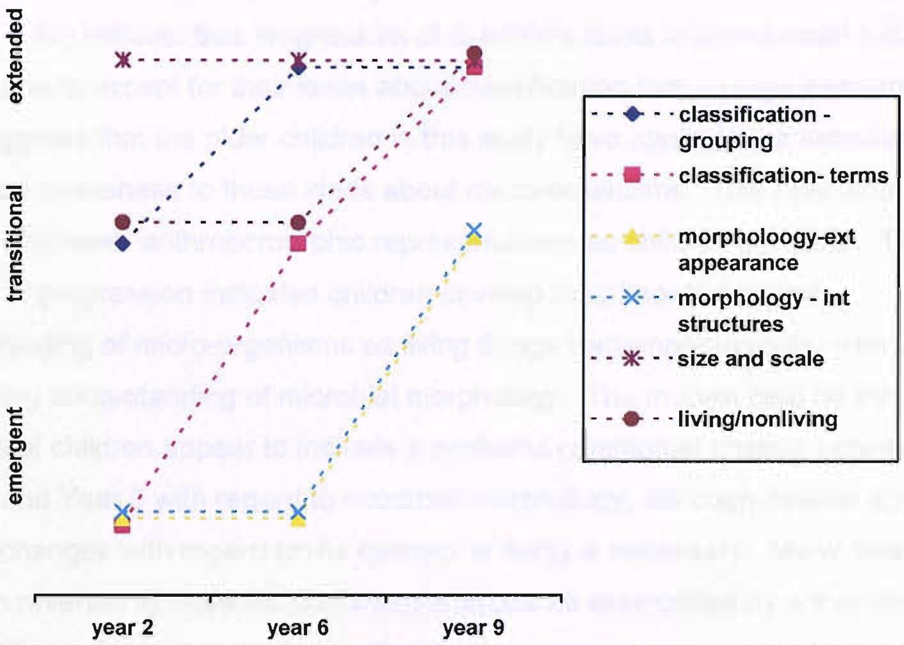


Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Figure 6.8b

Years 2, 6 and 9: Strongly held models (models held by the majority of children in each group)

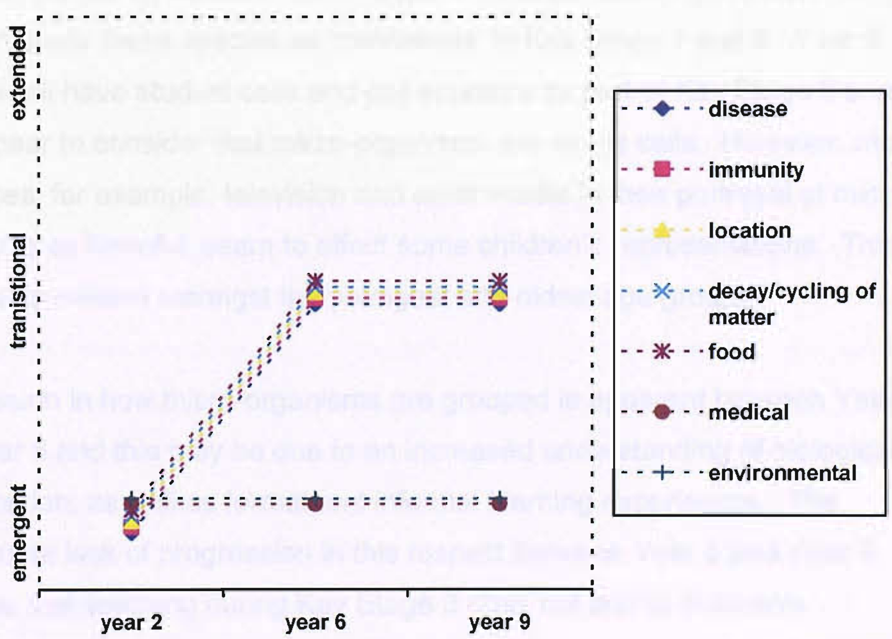


Figure shows the trend in children's ideas across Year 2, 6 and 9 and not a continuous data set

Knowledge and understanding of the concept of 'living', biological organisms and their classification has been shown to develop with age (Piaget, 1929; Carey, 1985; Braund, 1998; Tunnicliffe and Reiss, 1999) and is not thought to be fully developed until after the age of ten years. The trajectories of these concepts (Figure 6.8a) indicate that progression of children's ideas is pronounced between Year 6 and 9, except for their ideas about classification that change less radically. This suggests that the older children in this study have applied their increased biological awareness to these ideas about micro-organisms. This may also account for fewer anthropomorphic representations as children get older. The pattern of progression indicates children develop their knowledge and understanding of micro-organisms as living things contemporaneously with an increasing understanding of microbial morphology. The models held by the majority of children appear to indicate a profound conceptual change between Year 6 and Year 9 with regard to microbial morphology, although caution about similar changes with regard to the concept of living is necessary. Many Year 9 children reverted to more simplistic explanations as exemplified by a transitional model (Figure 6.1) when reasoning that micro-organisms are alive, which may suggest that only weak restructuring of the mental model has taken place (Carey, 1985). Prior learning, alongside a growing biological awareness, has probably influenced children's ideas about what micro-organisms look like. Many of Year 2 and Year 6 children consider micro-organisms to be small invertebrate animals. Children study these species as 'minibeasts' in Key Stage 1 and 2. Year 9 children will have studied cells and cell structure as part of Key Stage 3 science and appear to consider that micro-organisms are single cells. However, other influences, for example, television and other media in their portrayal of micro-organisms as harmful, seem to affect some children's representations. This is particularly evident amongst the youngest and oldest age groups.

Progression in how micro-organisms are grouped is apparent between Year 2 and Year 6 and this may be due to an increased understanding of biological classification, as well as formal and informal learning experiences. The subsequent lack of progression in this respect between Year 6 and Year 9 indicates that teaching during Key Stage 3 does not add to children's understanding about microbial classification, other than to increase knowledge of the variety of micro-organisms. Alternative classification systems based upon anthropocentric ideas about the virulence of micro-organisms were prevalent in all age groups.

Progression in many other conceptual areas (Figure 6.9) seems to be greatest between Year 2 and Year 6. The development of children's ideas between these two age groups is not surprising. As noted earlier, children's biological knowledge and understanding develops between these ages. More advanced models about disease and health, ecology and microbial applications in food production are held by the majority of Year 6 and Year 9 children. Learning opportunities both in and out of school, between Key Stage 1 and 2, appear to make a considerable contribution to children's increased knowledge and understanding. However, the lack of progression between Year 6 and Year 9 seems to indicate that any further learning opportunities do not influence this age group's ideas to the same extent. In addition, increased experience and maturity between Year 2 and Year 6 may also account for some of this progression, but it is puzzling that this does not seem to have made any difference to the oldest children's ideas.

A lack of progression across all age groups is evident with regard to some concepts. The majority of children in all age groups seem to know that micro-organisms are microscopic, which, given that some have not been taught it at school, indicates that formal learning is not the only influence on children's ideas. Other aspects of children's lives; for example, family customs and myths or television programmes, can contribute towards their knowledge and at times learning appears to be intuitive, as indicated by a Year 2 child who said, *'I just knowed it'* (tb3). All children found it difficult to grasp what microscopic means in terms of actual size and scale was poorly grasped. It seems that children's intuitive notions about the very small size of micro-organisms is not capitalised upon through formal teaching about size and scale; if it were, then it may help children to understand this difficult concept. At the other end of the hierarchy, emergent models are held, by the majority of children in all age groups, about the medical and environmental applications of micro-organisms. These key conceptual areas have important implications for future learning, especially with regard to biotechnology.

The typologies show that a minority of children in Year 6 and Year 9 hold emergent models about classification, living or non-living, immunity, location and cycling of matter which suggests that ideas have not developed, despite formal learning about these topics. In contrast, a minority of Year 2 children have extended ideas about classification, morphology, disease, immunity, location and medical applications. It seems at least for a small number of the youngest children in this study that their ideas are as sophisticated as the older age groups', without any formal learning. Progression in learning certain ideas seems to be haphazard; some young children can understand ideas at a complex level whilst some older children retain naïve ideas.

b. Summary of progression

Progression in children's ideas about micro-organisms is not straightforward; formal learning, everyday and personal experiences all influence children's ideas. Some of the youngest children in this study hold extended models of micro-organisms, whilst some older children retain naïve ideas. Progression of knowledge about what micro-organisms are and what they look like, generally develops across the whole age range, even though some older children still have naïve mental models about these concepts. Alternative ideas, contrary to what they have been taught, are retained by a high proportion of children in all of the conceptual areas related to microbial activity. Emergent models are held for medical and environmental applications of micro-organisms by the majority of children in all age groups indicating a lack of progress with respect to these concepts. Progress plateaus after Year 6 for the conceptual themes of disease, health and hygiene, ecology and microbial application in food technology, suggesting that after 11 years of age the majority of children's ideas about these concepts remain static. Whilst anthropocentric and negative ideas about micro-organisms tend to reduce with age their influence on the progression of children's ideas cannot be ignored. It seems that learning about micro-organisms, especially about what they do, is not simple.

6.3.3 Implications for learning and teaching

The findings and previous discussion about progression indicate that children are capable of learning about micro-organisms and that learning seems to occur in a range of contexts. Even some of the youngest children in this study can comprehend complex ideas, for example, immune response, or microbial classification, despite any formal learning. What has also been indicated is that progression in learning stabilises after Year 6 in respect of many conceptual themes, especially in connection with microbial activity. Alternative, or naïve, ideas are retained by some Year 6 and 9 children and, even when a more sophisticated model is expressed, explanations often rely upon simpler and perhaps more stable learning. In addition, negative and anthropocentric ideas about micro-organisms prevail throughout all age groups. These issues have implications for learning and teaching about micro-organisms.

a. Learning occurs in a range of contexts

A range of out of school contexts and experiences appears to have influenced children's ideas about micro-organisms; for example, the notion of the size of micro-organisms being related to their virulence. Constructivist theory recognises that children do not come to school with 'empty heads' (Bentley, 1989) and that these ideas are not necessarily in accord with an orthodox scientific view (Driver and Easley, 1978; Osborne and Freyberg, 1985; Driver, 1989; Osborne *et al.*, 1992). Furthermore, these ideas should not be ignored by teachers when planning and preparing learning and teaching sequences if good learning outcomes are to be achieved (Scott, 1987; Selley, 1999). By capitalising on these informal learning experiences, and making positive use of them, worthwhile integration of both formal and informal contexts can be achieved. The use of media images of micro-organisms, for example, from advertising, may help to develop a more scientific notion of microbial structure and begin to temper some of the strong emotional connotations that children appear to have about micro-organisms, such as how harmful they are.

b. Very young children can understand complex concepts

A minority of Year 2 children have shown that they hold extended models about micro-organisms with respect to their classification, morphology, location, as agents of diseases, immune response to infection from micro-organisms and medical applications of micro-organisms. These children may be assumed to have acquired these ideas from sources other than school lessons because the national curriculum for science does not require any formal teaching about micro-organisms at Key Stage 1. As the findings have shown, these children can understand complex ideas and it seems most appropriate that they are introduced to some aspects of microbiology at an earlier age than is currently required.

The Primary National Strategy (DfES, 2003) encourages teachers to take control of their own curriculum and be innovative; it seems that including opportunities, perhaps through cross-curricular topics which integrate science, geography, mathematics, or PSHE to learn about micro-organisms at this age may help to improve progression by adjusting the emergent ideas that many children in this age group have. This may also help to redress the balance with regard to the negative perceptions about micro-organisms which currently predominate this age group's ideas.

c. Many ideas are held in common

Findings show that ideas about micro-organisms are held in common by some children within each age group and across all age groups. It seems that learning about micro-organisms is not necessarily dependent upon being taught at particular ages and that some learning seems to be socially mediated via family and friends. Developing social interaction, as an aspect of pedagogy, by offering opportunities to discuss and reflect on currently held ideas about micro-organisms would allow children to challenge their peers and themselves through the medium of discourse. For example; children could be provided with cartoon images and electron micrographs of micro-organisms and be asked to discuss how best to portray micro-organisms to the general public.

Providing ways of developing ideas through argumentation in science are thought to be effective in challenging children's conceptual understanding (e.g. Newton *et al.*, 1999; Osborne *et al.*, 2004; Simon *et al.*, 2006). Using argumentation more frequently, as a pedagogical tool, could enable children to develop a more rational perspective about micro-organisms and may help to reduce the negative perception held by many children in all age groups. This could be achieved; for example, by reading newspaper articles that depict micro-organisms in a particularly negative manner and by facilitating small group debates about the issues and the science to which the article refers, children will have the opportunity to reconsider some of their pre-conceptions.

In addition, some ideas are commonly held by the majority of children in all age groups. Everyday experiences such as, not being able to see micro-organisms, or the severity of an illness, suggest that ontological reasoning gives rise to children's ideas about size and scale of micro-organisms. The notion that micro-organisms are 'microscopic' is generally recognised by children in all age groups. However, the scale and relative size of different micro-organisms is poorly understood. Integrating learning with other aspects of the curriculum; for example, mathematics and geography from the earliest age could provide children with a better understanding of what microscopic really means.

d. Progress stabilises after Year 6

The lack of progress in science made by children between Year 6 and Year 9 has been noted previously (Chapman, 2001; Galton, 2002). It seems that this is the case with respect to learning about micro-organisms, particularly, microbial activity. Children do, generally, seem to make good progress between Year 2 and Year 6 and learning appears to be retained by the majority of Year 9 children. Bridging units have been shown to be successful in aiding continuity and progression between primary and secondary school (Ryan, 2002; Davies and McMahon, 2004; Braund and Driver, 2005) and this may be initially helpful with regard to learning about micro-organisms. However, if children are to successfully undertake the requirements expected at Key Stage 4, the majority of children should at least have the basic knowledge exemplified by the extended model described earlier. Indeed, it would be ideal if this model could be extended even further. It seems that teaching and learning sequences about micro-organisms need to be more frequent during the early years of secondary school and be more topic based, providing opportunities to explore and develop knowledge and understanding in order to challenge emergent or transitional ideas (Meheut and Psillos, 2004). Incorporation of the study of micro-organisms in connection with other aspects of science, for example, decomposition and the cycling of matter, as well as beyond the confines of the science curriculum, for example, within food technology to provide 'concepts in context' (Fensham, 1994) may help to ameliorate these issues.

A greater emphasis on practical work that introduces and sustains work about micro-organisms, from Key Stage 1 through to Key Stage 3, may also help to maintain progress. For example; making bread and yogurt at Key Stage 1 would provide an introduction to the uses of micro-organisms. Key Stage 2 children could build on these experiences and explore the fermentation process more thoroughly, including the need for sterile conditions; for example, when making yogurt or ginger beer. Children might then understand the uses of beneficial micro-organisms and those that are not beneficial under certain conditions. The role of micro-organisms as decomposers could be then investigated by exploring what occurs in a compost heap. Key Stage 3 children would be in a position to undertake further practical work that explored the conditions required for these microbial activities. This would enable them to begin to develop their understanding of the metabolic processes of the micro-organisms involved. The examples of practical work described here offer progression and continuity from Key Stage 1 through to the end of Key Stage3.

Approaches such as this may begin to resolve some of the issues about lack of progression, especially at Key Stage 3 and may help to influence curriculum planners to include work about micro-organisms in a more comprehensive and worthwhile manner.

e. Simple explanations of complex ideas remain

The use of analogy and metaphor has been found to be effective in helping children understand abstract notions (Solomon, 1986; Duit and Glynn, 1996). Using the language of conflict between micro-organisms and the body can help children understand immune response and is a useful pedagogical tool to facilitate learning (Bentley and Watts, 1992). Some of the youngest children in this study provided similar explanations; however, more sophisticated and scientific explanations did not seem to develop with age (see section 5.2.3). Vocabulary noted in Chapter 5, such as 'white blood cells', associated with immune responses, is mentioned by older children but their ideas appear to be unclear about the function of white blood cells. Scientific language has been adopted but the concepts that underpin the terms are not necessarily fully understood (Bell and Freyberg, 1985; Harlen, 2001). Furthermore, the Year 9 children readily resort to metaphorical language, which seems to be taken quite literally, to explain their ideas. The use of these metaphors in teaching needs to be dealt with cautiously because it can cause this kind of confusion and, as children get older, they should be encouraged to understand that these models are metaphors rather than scientifically accurate descriptions (Dagher, 1994).

6.3.4 Implications for curriculum development

The implications for teaching and learning discussed in the previous sections of this chapter have clear consequences for curriculum development. Considerations for the curriculum include how to; capitalise on informal early learning, refocus the curriculum at Key Stage 3 to include aspects of microbiology other than those dealing with human health and develop the curriculum so that episodes of learning about micro-organisms are more frequent and topic-based across all Key Stages.

Findings indicate that very young children are capable of understanding complex concepts about micro-organisms. However, there is a clear mismatch between children's ability to comprehend these ideas and curriculum content. The Key Stage 1 curriculum does not include any specific reference to micro-organisms and yet children at this age do have a level of knowledge and understanding that could be used as the basis for formal learning. Adaptation of the curriculum would enable children to learn about micro-organisms earlier than they do at present. This would mean that, rather than starting 'cold' in Year 5 or 6, the Key Stage 2 curriculum would have a platform of formal learning episodes on which to build.

Progress plateaus in many of the conceptual themes investigated in this study after Key Stage 2. By the end of Key Stage 3 the majority of children do not have the expected knowledge and understanding about micro-organisms and misconceptions remain. The evidence in this study could support curriculum planners to provide more opportunities to teach about micro-organisms and expand the breadth of study at Key Stage 3 rather than focus solely on micro-organisms in relation to human health. This would build more coherently on the requirements in Key Stage 2. These alterations may improve levels of knowledge and understanding about micro-organisms so that progression does not plateau after Key Stage 2 and, avoid the majority of children failing to meet expectations in knowledge and understanding by the end of Key Stage 3. Developing schemes of work that incorporate the importance of micro-organisms within ecosystems and the technological applications of micro-organisms may help to maintain progress about these concepts. Children should then be in a better position to begin to understand the even more conceptually challenging ideas such as, the role of micro-organisms in genetic engineering and cycling of nutrients that await them at Key Stage 4.

Furthermore, many of the conceptual themes explored in this study are relevant to other aspects of science and the wider curriculum. Planners might reconsider the place of microbiology within the curriculum across all Key Stages so that teaching about micro-organisms is more closely integrated within broader aspects of science and other subject areas, such as health, ecology and biotechnology. Children would then have the opportunity to gain a better understanding of the role and importance of micro-organisms *per se* within these fields of knowledge and, as a result they may also develop a more comprehensive understanding of these complex concepts.

6.4 Limitations of the study

According to Wellington (1996), research is not just about a plan and empirical outcomes; it involves the researcher in reflection about what is happening throughout the project. There are issues that have occurred within this research project that are worth exploring further.

6.4.1 The research design

This study set out to elicit children's ideas about micro-organisms across three age groups using a modified survey design. The research design was developed to enable the research questions to be answered (Bryman and Burgess, 1994) and to capture children's ideas at particular ages (Robson, 1993; Verma and Mallick, 1999; Cohen *et al.,* 2007). According to Kerlinger (1969), a well thought out research design is essential to the positive outcome of any research project. The findings indicate that the research questions have been addressed, which suggests that the overall design was appropriate. However, having undertaken the research, several design issues became apparent.

The schools and pupils were selected to provide a sample that was as representative as possible of the whole school population. A range of schools were used within the primary phase, but only one large comprehensive school was used in the secondary phase. The design would undoubtedly be improved if, at least, one other secondary school had been included in the research. Furthermore, extending the research to include a larger cohort from the school population throughout England would provide a more comprehensive data set, which would increase the reliability of the findings.

The timing of the field work was planned to coincide with the end of each Key Stage, which represents the completion of a particular set of curriculum requirements. This was considered to be an appropriate time to capture data that was representative of the completion of any formal learning and teaching about micro-organisms for each age group. Findings indicate that influences other than formal learning affect children's ideas about micro-organisms. It may have been more appropriate to track children's ideas over a longer period of time, for example, the whole Key Stage. The time between the initial data collection and follow up interviews could have been extended, allowing for a more comprehensive overview of children's ideas at particular ages. Extending the time between different data collection methods would have had the further advantage of enabling a more detailed analysis of the initial data and, therefore, the possibility of a more insightful interview schedule being developed. In addition, the possibility of contamination of data would be reduced as the children would be less likely to remember what they had done, or said, during the initial stages of data collection, if a longer time period had elapsed.

The design imposed specific tasks upon the children; whilst efforts were made to provide a normal classroom environment there is the possibility of children performing for the task. A design in which the time scale was longer and included classroom-based observation, or analysis of discussion during lessons on micro-biology would have provided a more naturalistic setting. This may also have had the additional benefit of providing greater insights into how micro-biology is taught, as well as offering some comparison between the influences of formal and informal learning on children's ideas about micro-organisms.

As the research was designed as a survey, a questionnaire could have been administered to a much larger number of children initially, although arguments for not taking this approach have been discussed in Chapter 4. Nevertheless, if the perceived difficulties in questionnaire design for this wide age range had been overcome quantitative data would have been available. This data could have been subjected to statistical analysis to add to the validity of the findings and used as the basis for the rest of the data collection.

6.4.2 Research methods

Within the overarching methodological framework of a survey, a multiple method approach was adopted. According to Denzin and Lincoln (2003), this allows for the development of a rich data set as aspects of the research focus can be explored from different perspectives. However, using a variety of methods does not automatically ensure that data is valuable or valid. The research methods have to be fit for purpose in addressing the research questions and appropriate in collecting the type of data that is required (Kumar, 1996).

Findings indicate the adoption of a range of research methods that provided different types of data about the same conceptual theme; for example, drawings, brainstorms and interviews about the classification and morphology of micro-organisms, has produced a rich data set and has enabled the researcher to develop a comprehensive description of children's ideas about micro-organisms. Furthermore, the different research methods employed in this study did not preclude any age group from participating fully, for example, by being too difficult. Different data collection methods enquire about the same phenomenon from a different perspective, and produce different forms of data which may or may not corroborate; findings indicate that the planned methodological triangulation (Cohen *et al.* 2007) has added to the validity of the data. Two further issues, as a result of a multiple method approach, were recognised. Firstly, the different methods produced different levels of data, some that were rich and plentiful, and others not so; for example, data about micro-organisms as living things were generally richer from brainstorms compared to drawings (Tables 5.19, 5.21 and 5.23). Therefore, over-reliance on one method may have resulted in a paucity of data with a poor outcome for the research. However, as Reiss *et al.* (2002) suggest, drawings are extremely suited in eliciting children's ideas about the appearance of an item and provide a wealth of information without resorting to wordy descriptions. Secondly, some methods elicited better responses from some age groups than others. Responses from Year 9 to the drawing activity produced an 84.8% response rate, whereas response rates from Year 2 and Year 6 were 90.3% and 95.4% respectively. The familiarity of free drawing as an activity in primary compared to secondary school, especially in secondary science, may have been a factor. On the other hand, interviews with older children tended to be longer and more detailed which suggests that they were more comfortable talking to me than the younger children.

Some of the data collection methods were deliberately open-ended, free-thinking approaches and a rich variety of data were obtained from the drawings and the brainstorms. However, this may not have been as open-ended as might have been expected; for example, the instruction ' to draw a micro-organism' resulted in a large number of single 'cell' drawings, especially from Year 6 and 9. The result may be an artefact of the instruction rather than knowledge that micro-organisms are single-celled. Other data collection methods were more closed in their approach. The concept maps and interviews were planned in advance to elicit children's ideas about specific aspects of micro-organisms and this may have guided their thinking in particular ways to the exclusion of other ideas. The concept maps were particularly specific, having photographs that were chosen by me, although children were encouraged to add other pictures and propositions if they wished. In the event, only one child added pictures of leaves and a skeleton in relation to decaying items and connecting propositions between the photographs was an infrequent occurrence. This method may have been too prescriptive, inhibiting children to develop further connections between the photographs more fully. On a practical level, it would have been better if the photographs were already separated as cutting and pasting took children, especially the younger ones, a long time. Possible consequences are, firstly, that all children didn't have time to fully complete their maps and, secondly, they may have got tired of doing the activity and simply stopped. A more open-ended concept map may have been a better tool to obtain richer data, but, as I did not know the children and how proficient they were at concept mapping, a more directed approach was considered to be the most appropriate way. Interviews were largely in my control and a more open-ended approach might have allowed children to expand on their ideas. However, this was a follow-up to the previous data collection methods with the purpose of triangulating previous findings, rather than an initial exploratory process; therefore, a semi-structured interview, largely in my control was considered appropriate.

6.4.3 Ethical issues

From an ethical perspective children were not coerced to do any of the tasks. Children may have chosen simply not to take part which can account for the non-completion of some tasks. The relatively lower completion rates for Year 9 may be due to them being less likely to want to please, or less willing to cooperate. Whilst some Year 2 children may have misunderstood certain instructions, or chosen alternative tasks, for example, to draw different and, for them possibly more interesting things, which resulted in drawings such as 'my house' or 'my cat Mick'.

6.5 Research questions and contributions made by the research

The research set out to answer four research questions, in doing so, the research adopted an interpretive approach using multiple methods. Despite the limitations discussed in section 6.4, it has been possible to obtain data which when analysed answered the four research questions, which are:

1. Can children's ideas about micro-organisms at different ages be identified, described and quantified?
2. Can changes in how micro-organisms are conceptualized at different ages be identified, described and quantified?
3. Can coherent mental models be constructed that are representative of children's ideas about micro-organisms?
4. Can a typology be developed to illustrate progression of children's ideas about micro-organisms?

The multiple methods employed in this study have enabled children's ideas about micro-organisms to be investigated from a variety of perspectives with respect to the seven key themes identified in the literature review (see sections 2.3-2.9). These methods included visual representations, written descriptions, concept maps, and verbal explanations of micro-organisms and their activities. The approach yielded a rich data set for each age group and subsequent analysis of the data allowed commonalities and themes to emerge, so that it was possible to identify, describe and quantify the ideas children in each age group have about micro-organisms. As a result of this analysis comparisons between the age groups were carried out, so that changes in the ideas children have at different ages could be identified, described and quantified.

Hierarchical mental models (Figure 6.1) were derived from the data for each of the seven themes explored. The models for each theme were categorised as *extended*, *transitional* and *emergent* and characterise the ideas held by all of the children in the study. The mental models are therefore coherent and representative of children's ideas about micro-organisms. Differences in the prevalence of the different levels of sophistication for each model within the hierarchy, for each conceptual theme were identified between the age groups. These differences enabled typologies, typical for each age group, to be developed (Figures 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7). The typologies indicate the extent to which the models are representative of the ideas held by each age group; either strongly, moderately or weakly held and illustrate the progression of children's ideas about micro-organisms.

In answering the research questions, the research has made several contributions to knowledge. This study has added to the corpus of knowledge about children's ideas in science and especially in microbiology education. It is more comprehensive than any other previous work investigating children's ideas about micro-organisms. It considered a very wide range of concepts pertaining to micro-organisms, and sought to elicit ideas about these concepts across three consecutive age ranges, with the purpose of identifying the differences and changes children may have in terms of the progression of their ideas about micro-organisms. As a result, generalised hierarchical models that typify children's ideas across all three age groups have been developed. These are new and they could be used, as the basis for my future work, or as an analytical tool by others researching children's ideas about micro-organisms. In addition, the typologies developed from the models provide a deeper insight into the progression of ideas across the three age groups studied. Again, these are new and offer information about the development of children's ideas that could be used to inform curriculum developers and policy makers. I also believe that, like the models, they could be used to analyse others' work in this field.

A particular contribution to educational research is the development of a tool to elicit children's ideas using photographs to produce a concept map. Whilst concept maps have been used as a tool in science education to assess and elicit children's ideas, I am not aware of any other work using photographs to represent the concepts. The concept mapping using a photograph association technique (CoMPAT) is believed to be unique. It could be used by others exploring children's ideas about micro-organisms, as well as adapted and developed for use in other conceptual areas in science.

6.6 Recommendations for further research

Reflection on the research presented here has enabled me to consider the possibility of several avenues for further work that could be pursued.

The research showed that children learn about micro-organisms in a range of contexts and from a variety of experiences. Further work is needed in order to discern how, and to what extent these different contexts affect their ideas. In addition, this research, like previous studies, has taken place in western societies. It would be interesting to explore children's ideas about micro-organisms from a non-western perspective.

In connection with learning contexts and socio-cultural influences on children's ideas, exploration of the language used by children to express their ideas about micro-organisms is an area for further study and could be undertaken as a result of the findings presented here.

The research also highlighted that children's ideas are frequently influenced by negative attitudes towards micro-organisms. Phobic ideas about micro-organisms should be of concern to those engaged in teaching about micro-organisms and this needs to be explored more thoroughly as an area for further research.

An interesting avenue for further work, which has already been discussed in relation to the limitations of the research design and methods, would be to employ a more naturalistic research process, for example, using classroom observation rather than relying entirely on specific data collection methods which were not part of the children's normal classroom experience. This approach may, in part, help to answer the issue about learning contexts described above.

Findings have indicated that children's ideas at the end of Key Stage 3 are limited compared to the expected knowledge and understanding. It would be interesting to explore the effect of teaching and learning sequences in which children were taught about micro-organisms, using a socio-constructivist pedagogy, which included argumentation as a pedagogical tool.

Finally, this research project focussed on children prior to Key Stage 4. It would be interesting to develop this work with older children in the 14-19 age range in order to discover their ideas, compare them with the younger children focussed on in this study and relate this to their learning experiences.

6.7 Concluding comments

The research presented here has explored children's ideas about micro-organisms across three age groups and employed a survey methodology using multiple methods to answer the research questions. The research focussed on exploring children's ideas across specific conceptual themes pertinent to understanding micro-organisms and has shown that children from an early age can, and do learn about micro-organisms in a variety of contexts.

A particular contribution of this study is the development of a hierarchy of mental models, typical of children's ideas, for the key themes explored. In addition, what this research has established is that the prevalence of the different levels of model within the hierarchy for each conceptual theme alters between the age groups. Therefore it has been possible to develop typologies that are representative of the ideas for each age group. This study, unlike previous research, has examined the nature of progression of children's ideas with respect to understanding about aspects of the biology of micro-organisms. The prevalence of different levels of model within each typology has provided an indication of progression across the three age groups. Progression would seem to plateau after Year 6, especially with regard to understanding about microbial activity. Whilst some of the youngest children hold extended ideas about certain concepts such as morphology or immunity, some of the oldest retain emergent ideas.

Findings indicate that progression of ideas about micro-organisms is not straightforward and ideas do not necessarily become more complex or scientifically accurate with age. Alternative ideas about micro-organisms and their activities are found in all age groups. It is equally important to note that the some of the youngest children seem to be capable of understanding complex concepts and that their explanations, for example, making use of analogy and metaphor are similar to those of older children. Progression, with regard to most of the conceptual themes, does seem to occur between Year 2 and Year 6, although it remains static between Year 6 and 9 for many ideas associated with microbial activity. Year 9 children do seem, generally, to have more sophisticated ideas about microbial classification and appearance compared to the younger age groups. This increase in knowledge seems to be based upon learning about eukaryotic cells and cell structure at Key Stage 3, rather than learning about micro-organisms *per se*. Other ideas, such as the size of micro-organisms, or about micro-organisms as agents associated with diseases are almost universally held, although more sophisticated ideas about their actual or relative size, or the aetiology of microbial disease are not generally understood by any age group.

Two important themes have emerged from the data and were evident across the conceptual catalogue investigated in this study. The themes are commonly held by children in all age groups, although they do become less frequent as children get older. Firstly, the strong tendency to hold anthropocentric ideas about micro-organisms; in particular, the harm micro-organisms can cause humans. Secondly, the view that micro-organisms are harmful and essentially malevolent, without understanding that most microbial activity is benign, is widely held. This negative view of micro-organisms dominates many children's thinking in such diverse concepts such as classification, living, disease and decay.

It is clear that children do have many ideas about micro-organisms, and that a combination of everyday experiences and formal learning has shaped what they think. The development of learning sequences that facilitate progression in learning about micro-organisms from the earliest age, and that extend progression after the age of 11 years will be essential if children are to be enabled to meet the challenges that await them at Key Stage 4 and in their adult lives. Interest and curiosity need to be aroused, through practical work, as well as through other social interactions, such as dialogue and argument. These approaches will, hopefully, have the effect of dispelling the negative views of micro-organisms by promoting their positive role, for example, within ecosystems, as well as in current and future technologies. If curriculum developers were to respond to these aspirations a more balanced and scientifically literate view of micro-organisms could be established by children during their school career.

The purpose of this research project has been to develop and inform the research literature with respect to children's learning about micro-organisms. The findings may help to improve science education for all children.

Appendices

Appendix 1

Pilot study interview schedule
Hello my name is Jenny and I'm going to ask you some questions and ask you to draw a few things and look at some pictures. Don't worry though, this is not a test and whatever you say will be treated in confidence as a private conversation. I'd like to tape our conversation, is that OK with you? If you're not sure about anything, just say you're not sure rather than guess or make something up.

1. **Have heard you of**
   - bacteria?
   - viruses?
   - fungi?

   Do you know anything about them? Can you tell me?

   Have you heard of germs?
   What do you think is the most significant / important thing you know about them?
   Why?
   What is the least significant / important?
   Why?
   Do you know how you knew these things? / Where did your ideas come from?

2. **Have you ever seen a**
   - bacterium?
   - virus?
   - fungus?
   - germ?

   (Why not?)
   Where might you have seen them?
   How big do you think they are?
   Do you think they are all the same size?
   What do you think they look like? (Child to draw and label a picture)
   Do you think all micro-organisms look like this?
   Can you draw any different ones? (Child to draw and label alternatives)

3. **Are bacteria / viruses / fungi / germs alive?**
   How do you know?

4. **Where do you think you might find bacteria / viruses / fungi / germs?**

5. **What sort of things do bacteria / viruses / fungi / germs do?**

6. **Mouldy fruit probe**
   Do you know what this is?
   How did it get like this?
   What is responsible for this happening?
   What has happened to it?
   Is this a good thing or a bad thing?
   Why?
   Can you think examples when this (decay) would be a good thing?

7. **Yogurt probe**
   Do you know what this is?
   What is used to make it?
   Do you now how it is made?
   Do you know other foods that are made with the help of bacteria / viruses / fungi / germs?

8. **Sneezing person probe**
   Do you know what is happening in this picture?
   What has this person got?
   How did this person get it (the cold)?
   Is this how all diseases are caught?
   Have you ever had a cold?
   What happened to you?
   How did you get better?
   What sort of illnesses have you heard of?
   Do all illnesses come from bacteria / viruses / fungi / germs?

Do other animals have illnesses?
What causes the disease?
Do plants have illnesses?
What causes the diseases?

9. **Sorting activity**
Here are some pictures can you sort them into different groups to show which ones have anything to do with bacteria / viruses / fungi / germs?

Is there anything else you want to say about bacteria / viruses / fungi / germs that we haven't talked about?

That's been really helpful. I hope you've enjoyed talking to me. Thank you very much.

Appendix 2

Main study interview schedule
Hello my name is Jenny and I'd like to talk to you about what we did when I came in before. I'd just like to ask you some more things about what you did and follow up some other ideas. Don't worry though, this is not a test and whatever you say will be treated in confidence as a private conversation. I'd like to tape our conversation, is that OK with you? If you're not sure about anything, just say you're not sure rather than guess or make something up.

Name
Age
Girl / boy

1. **I was really interested in the picture you drew of a micro-organism / germ**
    - Can you tell me a little more about it and explain what the different features on it are?

Possible prompts
What do they do?
What do you think it would be like inside?
Do you think all micro-organisms look like this?
Possible prompts
Why? How are they different?
What kinds have you heard of? (B, V, F, G) How are they the same / different?

2. **You've added some interesting information about micro-organisms**
    - How did you know all of this?
    - Can you tell me anything else that you know about micro-organisms? E.g. what sort of things do they do?
    - What is the most important thing you know about micro-organisms? Why?
    - What is the least important? Why?
    - Do you think they are harmful / helpful? What sort of harmful / helpful things do they do?

3. **Size, structure, classification and variation.**
    - In real life have you ever seen a Germ / micro-organism / bacterium / virus / fungus?
    - How big do you think they are?
    - Do you think they are all the same size? How do they compare?

4. **A life form, microbial activity, life processes**
    - Are they alive?
    - How do you know? Why do you think these things show that they are alive?
    - Would you consider them to be plants, animals or neither?

5. **Ubiquity**
    - Where do you think you might find them?
    - What are they there for? What do they do?

6. **Decay and decomposition, cycling matter**
    - What has happened to the fruit? (mouldy peach probe)
    - What is responsible for this happening? How did it get like this?
    - What will happen to it eventually?
    - Is this a good thing or a bad thing?
    - Why?
    - Can you think examples when decay / rotting would be a good thing?
    - What happens inside this? (photograph of a compost heap)
    - How do you think this happens? Do micro-organisms have anything to do with it? How?
    - Is this a good thing or a bad thing?
    - Why?
    - What do you think micro-organisms have to do with the sewage works?
    - What sort of micro-organisms are there?
    - Why are they there?
    - Do you think micro-organisms have anything to do with nature / the environment? (cycling of nutrients) What do they do?

7. **Food production – yogurt, bread, cheese, soy sauce**
    - Do you think micro-organisms used to make any of the foods? Which ones?
    - How do they make it / what do they do?
    - What other foods do you think are made with the help of micro-organisms?

8. Diseases / disease prevention / immunity

- What do you think this person might be suffering from? What has this person got? (Sneezing person probe)
- How did this person get the cold?
- Is this how all diseases are caught? Other ways?
- Have you ever had a cold?
- How did you get it?
- How did you get better?
- Can you draw a picture and tell me what you think happened inside you to help you get better?
- What about other illnesses?
- How do you get them?
- How do you get better?
- Have you ever had any antibiotics? Why did you have them? Do you know how they work?
- Have you ever had any vaccinations? Why did you have them? Do you know how they work?
- What about other illnesses, do they come from micro-organisms?

That's been really helpful. I hope you've enjoyed talking to me. Anything you want to add? Thank you very much.

Appendix 3a

Coding scheme for drawings and brainstorms

Appearance/morphology

0	None
1	Amorphous
2	Coccus
3	Bacillus
4	Spiral
5	Tadpole
6	Animal like
7	Anthropomorphic
8	Abstract
9	Other

External features

0	None
1	Hairs
2	Tail
3	Facial features (eyes, nose, mouth)
4	Legs
5	Arms/hands/wings
6	Head
7	Spikes
8	Tentacles/antennae
9	Slime/ Substrate
10	Colour

Internal features

0	None
1	Internal mass/ spots/dots
2	Single large spot/dot/ nucleus
3	Outer layer/cell wall
4	Other - stated

Multiple repeated

0	No
1	Yes
2	

Names

0	None
1	Micro-organism/microbe
2	Germ
3	Bacteria
4	Virus
5	Fungi/mould
6	Different antonym
7	Same synonym
8	Bug/other
9	Specific

Living

0	None
1	Living
2	Movement /limbs
3	Nutrition/feeding/mouth
4	Sensitivity
5	Reproduction
6	Growth/development
7	Cellular structures

Microbial activity

0	None
1	Health/disease/hygiene
2	Food contamination/spoilage
3	Food production
4	Habitat /ecology/ environment/ location
5	Humans/ in/on
6	Decay

Size

0	None
1	Microscopic
2	Small
3	Actual size

Appendix 3b

Year 2

Data from drawings and brainstorms
N= 159 for drawings N=139 for brainstorm information (total numbers and percentages may be greater than 100%)

Data from drawings
159 = 90.3% of the total group drew a picture, 17 =9.7% did not attempt a drawing or drew an associated picture

Table
Morphology of drawings n=159

Appearance /morphology	Number	Percentage
Amorphous	20	12.8
Bacterial Cell	10	6.3
Animal like	43	27.0
Anthropomorphic	44	27.7
Abstract	48	30.2
Other -complex abstract structures	9	5.7

Table
Types of animal like drawings n=43

Types	Number	Percentage
Insects	13	30.2
Tadpoles	2	4.7
Worms/caterpillars	16	37.2
Other e.g. Frog, snail ,cartoon	14	32.6
Anthropomorphised drawings	34	79.1

Table
Types of abstract like drawings n=48

Types	Number	Percentage
Geometric – lines, circles, concentric circles, stars, triangles	40	74.1
Small dots	6	11.1
Irregular shapes	9	16.7

Table
External features of drawings n=159

External features	Number	Percentage
Hairs	17	10.7
Tail	10	6.3
Facial features	78	49.1
Legs	44	27.7
Arms/hands/wings	27	17.0
Head	20	12.6
Spikes	4	2.52
Tentacles/antennae	15	9.4
colour	26	16.4
none	52	31.4

Table
Facial features n=78

Types	Number	Percentage
Eyes	75	96.8
Mouth	57	73.1
Nose	19	24.4

Table
Internal features of drawings n=159

Internal features	Number	Percentage
Internal mass	30	18.9
Single large mass	3	1.9
Outer layer	1	0.6
other	6	3.8
none	123	77.4

Table
Multiple repeated drawings n=159

	Number	Percentage
Multiple repeated	55	34.6
Single drawings	104	65.4
Sub types n= 55		
Abstract: Geometric – lines, squiggles, circles, stars	18	32.7
Abstract :Small dots	4	7.3
Abstract: Irregular shapes	3	5.5
Amorphous	6	10.9
Animal like	15	27.3
Anthropomorphised	21	38.2

Table
Named drawings n=159

name	Number	Percentage
Micro-organism/microbe	0	0
Germ	50	31.4
Bacteria	0	0
Virus	0	0
Fungi/mould	0	0
Several terms used independently	0	0
Specific	0	0
Other – Animal, creatures, fleas, flies, little wormy things, maggots etc	11	6.9

Table
Attributes of living: annotations on drawing n=159 (10 comments)

name	Number	Percentage
Living	1	0.6
Movement	6	3.8
Nutrition	3	1.9
Sensitivity	2	1.3
Reproduction	1	0.6
Growth	1	0.6
Structure	0	0

Table
Microbial activity drawings and annotations n=159, (31 made at least one comment)

Activity	Number	Percentage
Disease, health, hygiene	18	11.3
Food contamination	0	0
Food production	0	0
Location	13	8.2
Humans	9	5.7
Decay	1	0.6

Table
Size associated with drawing and annotation n=159

size	Number	Percentage
Microscopic	Total 14	8.8
Small	8	5.0
Small drawing but no comment	42	26.4

Data from brainstorm activity

Table
Names provided n=139

Names	Number	Percentage
Micro-organisms/microbe	0	0
Germ	116	83.5
Bacteria	0	0
Virus	0	0
Fungi/mould	0	0
Several terms used	0	0
Specific	0	0
None	23	16.5

Table
Statements about living and/or characteristics of living n=139

features	Number	Percentage
Living	15	10.8
Movement	2	1.4
Nutrition	2	1.4
Sensitivity	0	0
Reproduction	7	5.0
Growth/development	0	0
Internal structure	0	0
None	117	84.2

Table
Statements about microbial activity n=139

	Number	Percentage
Disease, health and infection control	91	65.5
Food contamination/spoilage	0	0
Food production	0	0
Location	26	18.7
In/on humans	25	18.0
Decay	0	0
None	22	15.8

Table
Statements about size n=139

	Number	Percentage
Microscopic	11	7.9
Small	5	3.6
Actual size	0	0
none	123	88.5

Appendix 3b

Year 6

Data from drawings and brainstorm information
N=166 for drawings N=164 for brainstorm information (total numbers and percentages may be greater than 100%)

Data from drawings
166 =95.4 % drew a picture, 8 did not attempt a drawing or drew an associated picture e.g. a cut leg

Table
Morphology of drawings

Appearance /morphology	Number	Percentage
Amorphous	46	27.7
Bacterial Cell	41	24.7
Animal like	35	21.1
Anthropomorphic	17	10.2
Abstract	36	21.7
Fantasy/ Complex	5	3.0

Table
Types of animal like drawings n=35

Types	Number	Percentage
Insects	17	48.6
Tadpoles	8	22.9
Worms/caterpillars	4	11.4
Other e.g. Frog, cartoon	6	17.1
Anthropomorphised drawings	13	37.1

Table
Types of abstract like drawings n=36

Types	Number	Percentage
Geometric – lines, circles, concentric circles, stars, triangles	29	80.6
Small dots	15	41.7
Irregular shapes	3	8.3

Table
External features of drawings n=166

External features	Number	Percentage
Hairs	59	35.5
Tail	10	6.0
Facial features	31	18.7
Legs	26	15.7
Arms/hands/wings	9	5.4
Head	14	8.4
Spikes	7	4.2
Tentacles/antennae	11	6.6
colour	34	20.5
none	52	31.3

Table
Facial features n=31

Types	Number	Percentage
Eyes	31	100
Mouth	18	58.1
Nose	13	42.0

Table
Internal features of drawings n=166

Internal features	Number	Percentage
Internal mass	38	23.0
Single large mass	26	15.7
Outer layer	13	7.8
other	9	5.4
none	93	56.0

Table
Multiple repeated drawings n=166

	Number	Percentage
Multiple repeated	62	37.3
Single drawings	106	63.8
Sub types n=62		
Abstract: Geometric – lines, squiggles, circles, stars	14	22.9
Abstract :Small dots	11	17.7
Abstract: Irregular shapes	3	4.8
Amorphous	19	30.6
Animal like	6	9.7
Anthropomorphised	4	6.5

Table
Named drawings n=166

name	Number	Percentage
Micro-organism/microbe	64	38.6
Germ	27	16.1
Bacteria	15	9.0
Virus	3	1.8
Fungi/mould	0	0
Several terms used	18	10.8
Specific	1	0.6
Other - Animal	3	1.8

Table
Usage of multiple terms in drawings and brainstorms (n=18 drawings, n=89 brainstorms)

	Percentage of drawings	Percentage of brainstorms
terms used interchangeably	27.8	69.6
terms used independently	72.2	30.4

Table
Attributes of living: annotations on drawing n=166

name	Number	Percentage
Living	8	4.8
Movement	21	12.6
Nutrition	1	0.6
Sensitivity	8	4.8
Reproduction	9	5.4
Growth	1	0.6
Structure	4	2.4

Table
Microbial activity drawings and annotations n=166

Activity	Number	Percentage
Health and disease	10	6.0
Food contamination/decay	6	3.6
Food production	6	3.6
Location	13	7.8
Humans	15	9.0
Decay	1	0.6

Table
Size associated with drawing and annotation n=166

size	Number	Percentage
Microscopic	22	13.3
Small	16	9.6
Actual size	2	1.2

Data from brainstorms

Table
Names provided n=164

Names	Number	Percentage
Micro-organisms/microbe	136	82.9
Germ	61	37.2
Bacteria	48	29.3
Virus	5	3.0
Fungi/mould	4	2.4
Several terms	89	54.2
Specific	13	7.9
None	14	8.5

Table
Statements about living and/or characteristics of living n=164

features	Number	Percentage
Living	42	25.6
Movement	6	3.7
Nutrition	6	3.7
Sensitivity	1	0.6
Reproduction	39	23.8
Growth/development	1	0.6
Internal structure	1	0.6
None	78	47.6

Table
Statements about microbial activity n=164

	Number	Percentage
Disease, health, infection control	102	62.2
Food contamination/spoilage	27	16.5
Food production	35	21.3
Location-	50	30.5
In/on humans	32	19.5
Decay	6	3.7
None	26	15.8

Table
Statements about size n=164

	Number	Percentage
Microscopic	39	23.8
Small	33	20.1
none	92	56.1

Appendix 3b

Year 9

Data from drawings and brainstorms
N=89 for drawings N=78 for brainstorm information (total numbers and percentages may be greater than 100%)

Data from drawings
89 = 84.8 % of the total group (n=105) drew a picture, 16=15.2%

Table
Morphology of drawings n=89

Appearance /morphology	Number	Percentage
Amorphous	48	54.0
Bacterial Cell	15	16.9
Animal like	8	9.0
Anthropomorphic	9	10.1
Abstract	14	15.7
Other e.g. sperm, animal, plant cells	11	12.4

Table
Types of animal like drawings n=8

Types	Number	Percentage
Insects	3	37.5
Tadpoles	0	0
Worms/caterpillars	4	50.0
Other e.g. Frog, cartoon	1	12.5
Anthropomorphised drawings	7	87.5

Table
Types of abstract like drawings n=14

Types	Number	Percentage
Geometric – lines, circles, concentric circles, stars, triangles	13	92.9
Small dots	1	7.2
Irregular shapes	1	7.2

Table
External features of drawings n=89

External features	Number	Percentage
Hairs	10	11.2
Tail	5	5.6
Facial features	16	18
Legs	7	7.9
Arms/hands/wings	1	1.1
Head	1	1.1
Spikes	1	1.1
Tentacles/antennae	6	6.7
colour	1	1.1
none	65	73.0

Table
Facial features n=16

Types	Number	Percentage
Eyes	15	93.8
Mouth	10	63.0
Nose	0	0

Table
Internal features of drawings n=89

Internal features	Number	Percentage
Internal mass	26	29.2
Single large mass	41	46.1
Outer layer	30	33.7
other	0	0
none	33	37.1

Table
Multiple repeated drawings n=89

	Number	Percentage
Multiple repeated	9	10.1
Single drawings	80	89.9
Sub types n= 9		
Abstract: Geometric – lines, squiggles, circles, stars	4	44.4
Abstract :Small dots	0	0
Abstract: Irregular shapes	0	0
Amorphous	2	22.2
Animal like	2	22.2
Anthropomorphised	2	22.2
Bacterial cell	2	22.2

Table
Named drawings n=89

name	Number	Percentage
Micro-organism/microbe	24	30.0
Germ	9	10.1
Bacteria	10	11.2
Virus	5	5.6
Fungi/mould	0	0
Several terms used	94	10.1
Specific	1	1.1
Other - Animal , plant cell, animal cell etc	9	10.1

Table
Attributes of living: annotations on drawing N=89 (36 made at least one comment)

name	Number	Percentage
Living	3	3.4
Movement	7	7.9
Nutrition	1	1.1
Sensitivity	0	0
Reproduction	0	0
Growth	0	0
Structure	28	31.5

Table
Microbial activity drawings and annotations n =89 (4 made any comment)

Activity	Number	Percentage
Disease, health and infection control	4	4.5
Food contamination	0	0
Food production	0	0
Location	0	0
Humans	1	1.1
Decay	0	0

Table
Size associated with drawing and annotation n=89 n=13 made a comment

size	Number	Percentage
Microscopic	5	5.6
Small	8	9.0
Small drawing but no comment	35	39.3

Table
Usage of multiple terms in drawings and brainstorms (n=9 drawings, n=41 brainstorms)

	Percentage of drawings	Percentage of brainstorms
terms used interchangeably	55.6	97.6
terms used independently	44.4	2.4

Data from brainstorming activity

Table
Names provided n=78

Names	Number	Percentage
Micro-organisms/microbe	40	51.3
Germ	25	32.1
Bacteria	35	44.9
Virus	16	20.5
Fungi/mould	1	1.3
Several terms	41	52.6
Specific	18	23.1
Other	10	12.8
None	9	11.5

Table
Statements about living and/or characteristics of living n=78

features	Number	Percentage
Living	30	38.5
Movement	2	2.6
Nutrition	1	1.3
Sensitivity	0	0
Reproduction	3	3.8
Growth/development	1	1.3
Internal structure	18	23.1
None	30	38.5

Table
Statements about microbial activity n=78

	Number	Percentage
Disease, health and infection control	31	39.7
Food contamination/spoilage	2	2.6
Food production	6	7.7
Location	6	7.7
In/on humans	11	14.1
Decay	1	1.3
None	32	41.0

Table
Statements about size n=78

	Number	Percentage
Microscopic	35	44.9
Small	17	21.8
none	26	33.3

Appendix 3c

Year 2: Drawings / External appearance

codename	external appearance	notes and annotation	sorting code
si30	no picture	you can't see germs	0
si45	no picture	you can't see germs	0
hai32	none		0
hai52	no picture	associated with animals etc	0
hai55	no picture	associated with person and food	0
hai63	no picture	associated with drinks	0
hai79	no picture	associated with drinks	0
tb32	n/a	drawing of house and mother	0
tb1	n/a	broken buildings/sand	0
tb30	n/a	drawing of a ladybird - a lady bird is a small insect full of germs	0
tb34	n/a	drawing of rabbit and a girl	0
tb41	n/a	picture of a person and a cat	0
tb45	n/a	drawings of a cat and a dog	0
tb47	n/a	drawing of soil - soil has germs inside it	0
si26	n/a	picture of a girl sneezing	0
si41	n/a	picture of a girl with chicken pox	0
tb36	n/a	picture of a fly	0
tb2	amorphous	I think they look like a dirty inside with bubbles in it	1
tb8	amorphous		1
tb14	amorphous		1
si2	amorphous	a sploge	1
si7	amorphous		1
si9	amorphous	slimey, watery, gooey, drippy	1
si31	amorphous	germs are sweaty and shiny	1
hai3	amorphous		1
hai17	amorphous		1
hai29	amorphous		1
hai31	amorphous	slimey, scaley	1
hai34	amorphous		1
hai36	amorphous		1

hai38	amorphous	wiggerly germ	1
hai45	amorphous		1
hai49	amorphous	wiggerly germ	1
hai77	amorphous		1
tb10	bacillus		3
tb16	bacillus		3
tb43	bacillus		3
si46	bacillus		3
hai57	bacillus		3
hai61	bacillus		3
hai76	bacillus		3
tb29	spirillum	I think maggots might be germs	4
tb39	animal like	labelled drawings of a spider, slug, ladybird	6
tb3	animal like insect	insect	6
tb6	animal like	anthropomorphized, worms, insects little wormy things	6
tb7	animal like	anthropmorphised worms, insects, snails, spiders	6
tb13	animal like	anthropmorphised animal monster	6
tb18	animal like	anthropomorphised slug	6
tb22	animal like	tortoise	6
tb24	animal like	anthropomorphised bug	6
tb33	animal like	anthromorphised worms	6
tb35	animal like	anthroporphised worms	6
tb44	animals	drawings of a slug, spider, ladybird, snail - these are germs, some anthropomorphised	6
si4	animal like	worms and small animal	6
si8	animal like	insect	6
si10	animal like	anthropomorphised worms	6
si12	animal like	insect	6
si15	animal like	anthropomorphised worms	6
si17	animal like	labelled ants	6
si19	animal like	cartoon monster	6
si34	animal like	anthropomorphised worms, cartoon cat	6
si39	animal like	anthropomorphised worms	6
si42	animal like	anthropomorphised insect it looks like a beetle	6
si44	animal like	anthropomorphised worm, my germs look like worms bit it isn't (a worm)	6

si47	animal like	cartoon animal	6
si49	animal like	anthropomorphised worms	6
hai11	animal like	anthropomorphised worm	6
hai12	animal like	cartoon monster	6
hai14	animal like	anthropomorphised worms	6
hai15	animal like	various cartoon like monsters	6
hai25	animal like	cartoon like monster snake for a tail	6
hai41	animal like	anthropomorphised tadpole	6
hai43	animal like	anthropomorphised tadpole	6
hai65	animal like	anthropomorphised caterpillars	6
hai28	animal like	cartoon like	6
hai74	animal like	fantasy animal	6
hai73	animal like	fantasy animal?	6
hai21	anthropomorphic and animal like	they're big blobby things and sometimes they're round anthropomorphised animals	6,7
tb9	anthropomorphic	cartoon like	7
tb15	anthropomorphised	monster cartoon like	7
tb17	anthropmorphised	monster cartoon like	7
tb21	anthropomorphic	cartoon like	7
tb28	anthropomorphic	cartoon like maggot	7
tb40	anthropomorphic		7
tb42	anthropomorphic		7
si1	anthropomorphic	cartoon like	7
si3	anthropomorphic	cartoon monster	7
si5	anthropomorphic		7
si13	anthropomorphic		7
si16	anthropomorphic		7
si20	anthropomorphic		7
si22	anthropomorphic	slimey cartoon like	7
si32	anthropomorphic	a face	7
si35	anthropomorphic	I think germs look like little bubbles	7
si38	anthropomorphic		7
si48	anthropomorphic	cartoon monsters	7
hai1	anthropomorphic	cartoon like monster	7
hai6	anthropomorphic	anthropomorphised cartoon monster it wouldn't have a smiley face because they're not	7

		friendly	
hai8	anthropomorphic	cartoon like	7
hai16	anthropomorphic	a cartoon face	7
hai19	anthropomorphic	cartoon	7
hai30	anthropomorphic	carton like- heart shape, amorphous	7
hai42	anthropomorphic		7
hai48	anthropomorphic	cartoon	7
hai50	anthropomorphic	cartoon person	7
hai51	anthropomorphic	cartoon face	7
hai58	anthropomorphic	cartoon person/animal	7
hai59	anthropomorphic	cartoon	7
hai60	anthropomorphic	cartoon monster	7
hai67	anthropomorphic	cartoon monster	7
hai68	anthropomorphic	cartoon monster	7
hai69	anthropomorphic	cartoon person	7
hai70	anthropomorphic	carton monster	7
hai72	anthropomorphic	cartoon monster face	7
hai78	anthropomorphic	cartoon monster	7
tb4	abstract	circles drawn on teeth - sugar on teeth	8
tb5	abstract	zig zag shape, associated with a cat and a dog	8
tb12	abstract	circles with hairs	8
tb19	abstract	like clouds	8
tb23	abstract	rings and circles	8
tb26	abstract	geometric oval shape	8
tb27	abstract	squiggles, lines	8
tb31	abstract	circles	8
tb37	abstract	a rainbow shape	8
tb38	abstract	circles	8
si14	abstract	concentric circles	8
si21	abstract	random shapes	8
si23	abstract	circle	8
si24	abstract	variety of shapes	8
si25	abstract	geometric - tear shape	8
si27	abstract	lines and squiggles	8

si28	abstract	rectangle	8
si29	abstract	circle	8
si32	abstract	irregular shape	8
si33	abstract	circles	8
si37	abstract	geometric	8
si43	abstract	I think germs look like dots	8
hai2	abstract	dots/ circles	8
hai4	abstract	irregular shape	8
hai5	abstract	circle	8
hai7	abstract	dots	8
hai9	abstract	geometric - circles and rectangles	8
hai10	abstract	circle and lines	8
hai18	abstract	spikey ,dotty	8
hai20	abstract	irregular shape, circle	8
hai23	abstract	irregular shaped, worm like, circles	8
hai35	abstract	circle	8
hai39	abstract	concentric circles with dots	8
hai44	abstract	various shapes	8
hai47	abstract	circles	8
hai54	abstract	rectangles on a tree	8
hai56	abstract	dots, lines	8
hai62	abstract	circles and other shapes	8
hai64	abstract	irregular	8
hai66	abstract	dots	8
hai71	abstract	dots, curved when enlarged	8
hai13	other	abstract /animal like/cell like - tadpole/sperm	9
hai80	other	complex, animal features	9
tb25	other	complex/abstract structure	9
si6	other	abstract/complex	9
si18	other	abstract/complex	9
si36	other	complex/abstract structure	9
si40	other	gooey complex /abstract structure	9
hai37	other, complex/fantasy		9
hai22	amorphous, cocci	cells are sometimes a germ- special cells, a liquid that is a germ	1,2

hai33	amorphous, animal like	anthropomorphised insect like	1,6
si11	amorphous and abstract	circles	1,8
hai40	animal like, cocci	anthropomorphised caterpillars, cocci labeled cells	2,6
hai24	animal like and anthropomorphic	anthropomorphised snail, insect	6,7
hai46	anthropomorphic and animal like	anthropomorphised worm, and cartoon	6,7
hai27	animal like, abstract, anthropomorphic	anthropomorphised mammal, a face, circles	6,7,8
hai53	abstract, anthropomorphic animal like	circle, cartoon person, insects	6,7,8
hai26	animal like, abstract	anthropomorphised, insect, heart	6,8
tb20	abstract and anthropomorphised animal like	circles, anthropomorphised mammal	6,8
tb11	abstract and anthropomorphic	geometric shapes, cartoon like	7,8
hai75	anthropomorphic enlarged version, abstract various shapes	cartoon face, irregular	7,8

Appendix 3c

Year 6: Drawings / External appearance

codename	external appearance	notes and annotation	sorting code
sj2	amorphous		1
sj3	amorphous		1
sj8	amorphous		1
sj15	amorphous		1
sj25	amorphous		1
sj31	amorphous		1
sj34	amorphous	I think two or three are joined together	1
sj41	amorphous		1
sj44	amorphous		1
sj51	amorphous		1
sj55	amorphous		1
sj56	amorphous	squashy, stuck together	1
haj5	amorphous		1
haj6	amorphous		1
haj14	amorphous	it's a wiggerly shape	1
haj17	amorphous		1
haj19	amorphous		1
haj20	amorphous		1
haj23	amorphous	no particular shape	1
haj35	amorphous		1
haj37	amorphous		1
haj54	amorphous	a curve with a cell inside because it seems just right	1
haj55	amorphous	a blob because the blobs come together and get bigger	1
haj66	amorphous		1
haj68	amorphous		1
sm1	amorphous	good and bad, the majority will make this good or bad	1
sm2	amorphous		1
sm4	amorphous		1
sm7	amorphous		1
sm10	amorphous		1

sm16	amorphous		1
sm18	amorphous		1
sm26	amorphous		1
sm27	amorphous	small and wiggly	1
sm30	amorphous		1
sm31	amorphous		1
sm32	amorphous		1
sm37	amorphous		1
sm38	amorphous		1
sj27	cocci		2
sj30	cocci		2
sj33	cocci		2
sj50	cocci		2
sj54	cocci		2
sm3	cocci		2
sj1	bacillus		3
sj7	bacillus		3
sj13	bacillus		3
sj14	bacillus		3
sj20	bacillus		3
sj26	bacillus		3
sj28	bacillus		3
sj29	bacillus		3
sj36	bacillus	splitting	3
sj38	bacillus		3
sj42	bacillus		3
sj45	bacillus		3
haj11	bacillus		3
haj13	bacillus		3
haj26	bacillus		3
haj30	bacillus		3
haj33	bacillus		3
haj41	bacillus		3
haj42	bacillus		3

haj71	bacillus		3
haj69	bacillus		3
sm12	tadpole		5
sj57	tadpole		5
haj25	tadpole		5
haj28	tadpole		5
haj44	tadpole		5
haj48	tadpole		5
haj61	tadpole		5
haj46	animal like	a hairy insect thing its green	6
haj65	animal like	a very hairy infectious insect	6
sj5	animal like	cartoon	6
sj19	animal like	anthropomorphized - cartoon like	6
haj3	animal like, several types	anthropomorphized insects, caterpillars, other	6
haj4	animal like	anthropomorphized caterpillar/worm	6
haj9	animal like	insect	6
haj10	animal like	caterpillar/worm	6
haj27	animal like	octopus-cartoon like	6
haj43	animal like	insect	6
haj51	animal like	insect	6
haj58	animal like	anthropomorphic insect	6
haj59	animal like	anthropomorphic insect	6
haj62	animal like	anthropomorphic insect	6
haj64	animal like	a red little bug - anthropomorphized	6
haj72	animal like	anthropomorphized- cartoon like	6
haj74	animal like	frog	6
sm5	animal like	insect-ant	6
sm6	animal like	insect	6
sm13	animal like	insect	6
sm14	animal like	anthropomorphized insect	6
sm20	animal like	insects	6
sm25	animal like	anthropomorphized insect	6
sm28	animal like	anthropomorphized tadpoles/worms	6
haj73	animal like	hair	6

sj37	animal like and anthropomorphic	anthropomorphized insects	6
sm33	animal like	anthropomorphized, legs, eye	6
sm11	anthropomorphic	eyes, legs	7
haj60	anthropomorphic	eyes, legs, skin	7
sj24	anthropomorphic		7
sj52	anthropomorphic		7
sj53	anthropomorphic	drawings of good and bad	7
haj1	anthropomorphic		7
haj8	anthropomorphic	carton like – ARRH	7
haj18	anthropomorphic	cartoon like	7
haj22	anthropomorphic	cartoon like	7
haj32	anthropomorphic	cartoon like	7
haj38	anthropomorphic		7
haj39	anthropomorphic		7
haj52	anthropomorphic	gooey	7
sm17	anthropomorphic		7
sm39	anthropomorphic		7
sj35	anthropomorphic	cartoon like	7
haj16	abstract	various irregular shapes	8
haj24	abstract	various irregular shapes	8
sj6	abstract	concentric circles filled with small dots	8
haj57	abstract	concentric circles with a tail, any shape	8
haj78	abstract	various irregular shapes	8
haj75	abstract	circles - see through transparent circles in the air	8
sm21	abstract	circles and squiggles	8
sm34	abstract	irregular circles	8
haj7	abstract	circles and dots labelled micros in spit	8
sj9	abstract	a spikey circle and a spiral labelled two types of bacteria	8
sj10	abstract	spiral labelled bacteria, a sphere with protuberances labelled virus	8
sj17	abstract	circle with spikes around it	8
sj18	abstract	squiggles	8
sj23	abstract	circular with protuberances	8
sj32	abstract	black dots	8
sj39	abstract	small lines	8

sj40	abstract	small dots	8
sj48	abstract	sqiggles, spirals, small dots	8
haj15	abstract	circles and squiggles	8
haj21	abstract,	tiny dots on a dish-agar plate	8
haj29	abstract	concentric circle labelled a circle small micro-organisms inside as small dots	8
haj36	abstract	round small dots inside – little ones	8
haj45	abstract	circle with spikes around the edge	8
haj47	abstract	dots/lines	8
haj56	abstract	spikey circles and dots	8
haj67	abstract	concentric circles	8
sm8	abstract	tiny dots	8
sm9	abstract-	small dots labelled the size of micro-organisms	8
sm22	abstract	star	8
sm23	abstract	small dots	8
sm24	abstract	star	8
sm29	abstract	small dots	8
sm35	abstract	star and triangles	8
sj49	abstract	squiggles	8
sj22	complex	lots of spot full of smaller microbes	9
haj40	complex	reproducing tunnel	9
haj50	complex	reproducing tunnel	9
haj53	complex		9
haj77	complex		9
sj12	bacillus, cocci, amorphous		1,2,3
sj43	cocci, abstract, amorphous	spiral - bacteria, circle with spikes	1,2,8
haj63	amorphous(germ), bacillus (bacteria)		1,3
haj31	amorphous(germ), cocci (bacteria)		1,2
sj11	amorphous, rods, cocci, spiral		1,2,3,4
sj16	amorphous, bacillus		1,3
sj4	amorphous (germs) abstract(bacteria and virus)	spirals labeled bacteria, a sphere with protuberances labeled virus, amorphous shapes labeled germs	1,8
haj76	rods, cocci,		2,3
haj12	cocci, bacillus, spiral	flagellated forms, spirilla, single coccus, diplococci in pairs, streptococci in chains	2,3,4

sj21	abstract/animal like	I think they are worm-like creatures	8,6
ha49	abstract	complex - little bugs shown as circle with small dots	8,9

Appendix 3c

Year 9: Drawings / External appearance

Code name	external appearance	annotation/notes	sorting code
ca21	no picture		0
ca22	no picture		0
ca26	no picture		0
ca30	no picture		0
ca36	no picture		0
ca46	no picture		0
ca52	no picture		0
ca58	no picture		0
ca60	no picture		0
ca65	no picture		0
ca68	no picture		0
ca70	no picture		0
ca72	no picture		0
ca88	no picture		0
ca98	no picture		0
ca102	no picture		0
ca3	amorphous	a single celled micro-organism	1
ca9	amorphous		1
ca10	amorphous		1
ca12	amorphous		1
ca13	amorphous		1
ca16	amorphous		1
ca27	amorphous		1
ca29	amorphous		1
ca31	amorphous		1
ca33	amorphous		1
ca34	amorphous		1
ca35	amorphous		1
ca42	amorphous		1
ca43	amorphous		1

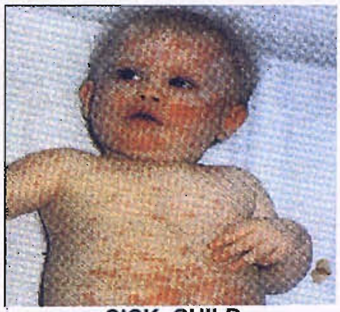
ca47	amorphous	anthropmorphised	1
ca48	amorphous		1
ca49	amorphous		1
ca53	amorphous		1
ca61	amorphous		1
ca62	amorphous		1
ca66	amorphous		1
ca67	amorphous	labelled -an animal cell	1
ca75	amorphous		1
ca77	amorphous		1
ca81	amorphous		1
ca82	amorphous		1
ca83	amorphous		1
ca84	amorphous		1
ca91	amorphous		1
ca92	amorphous		1
ca93	amorphous		1
ca94	amorphous		1
ca96	amorphous		1
ca100	amorphous	like a plant cell	1
ca104	amorphous		1
ca106	amorphous		1
ca107	amorphous		1
ca44	coccus		2
ca45	coccus		2
ca89	coccus		2
ca97	coccus		2
ca99	coccus		2
ca5	bacillus	single celled organism	3
ca20	bacillus		3
ca32	bacillus		3
ca38	bacillus		3
ca50	bacillus		3
ca57	bacillus		3

ca63	bacillus		3
ca80	bacillus		3
ca37	spiral		4
ca7	animal like	insect like monster	6
ca11	animal like	insect like	6
ca14	animal like	insect like	6
ca85	animal like	caterpillar/worm	6
ca95	animal like	caterpillar/worm	6
ca1	anthropomorphic	bacteria, germ - anthropomorphic monster drawn	7
ca69	anthropomorphic	sharp teeth, anthropomorphised monster	7
ca76	anthropomorphic	unpleasant a nasty thing that goes in your body and destroys everything, suitcase of bad stuff, yucky things	7
ca78	anthropomorphic	sharp teeth - wants to eat white blood cells	7
ca87	anthropomorphic	fang like teeth	7
ca6	abstract	geometric- triangles, rectangles	8
ca17	abstract	star	8
ca25	abstract	squiggles and lines	8
ca28	abstract	several shapes drawn - geometric	8
ca56	abstract	geometric - oval	8
ca71	abstract	wiggly line	8
ca74	abstract	geometric	8
ca79	abstract	geometric- short lines and 'spikes', linked to picture of hospital	8
ca90	abstract	a dot	8
ca103	abstract	geometric- a rectangle with 'cell' organelles in it	8
ca4	other	sperm cell drawn	9
ca41	other	virus like structure	9
ca59	other	labeled it a plant cell	9
ca2	amorphous, other	sperm cell drawn	1, 9
ca18	amorphous, other	virus like structure drawn	1, 9
ca8	amorphous, other	sperm cell drawn	1,9
ca39	amorphous, other	sperm cell drawn - tail to wiggle, acid on head,	1,9
ca54	amorphous, other	sperm cell drawn	1,9
ca55	amorphous, coccus, anthropomorphic	several types drawn	1,2,7
ca51	amorphous, anthropomorphic	bacteria- amorphous, germ and virus anthropomorphised monsters,	1,7

ca86	amorphous, anthropomorphic	different types drawn	1,7
ca15	amorphous, anthropomorphic, other	several types drawn	1,7,9
ca19	abstract, amorphous	a small dot - enlarged version drawn	1,8
ca23	abstract, amorphous	dust particles'	1,8
ca64	bacillus spiral, other	sperm like cell drawn	3,4,9
ca24	animal like, other	sperm, anthropomorphised octopus	6, 9
ca101	abstract, animal like	worm like creature drawn + small repeated circles 'worm is a germ'	6,8
ca105	abstract, animal like	worm like creature drawn + small repeated circles 'worm is a germ'	6,8

Appendix 4a Photographs used for concept maps

A COMPOST HEAP



SICK CHILD

VACCINATION

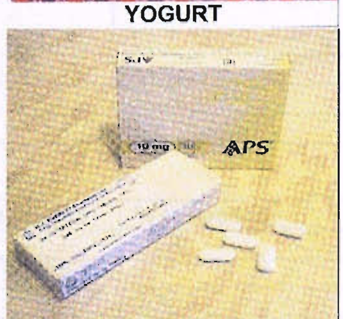
BEER

MOULDY BREAD

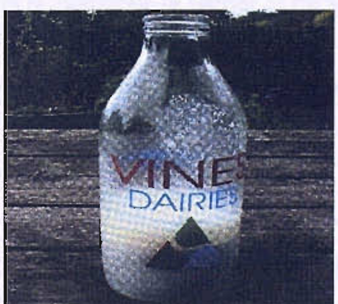
YOGURT

BLEACH

A SEWAGE WORKS



ANTIBIOTICS



SOUR MILK

BREAD

MICRO-ORGANISMS

GERMS

Appendix 4b

Summary data: Year 2 photograph association concept maps
N=173

Photograph	Total Score =4	%	Total Score =3	%	Total Score=2	%	Total Score=1	%	Total Score=0	%
Sick child	4	2.3	22	12.7	68	39.3	35	20.2	44	25.4
Vaccination	0	0	2	1.2	14	8.1	23	13.3	134	77.5
Antibiotics	0	0	1	0.6	17	9.8	14	8.1	141	81.5
Bleach	0	0	2	1.2	4	2.3	35	20.2	132	76.3
Bread	0	0	0	0	0	0	3	1.7	173	98.3
Beer	0	0	0	0	0	0	28	16.2	145	83.8
Yogurt	0	0	0	0	0	0	7	4.0	166	96.0
Mouldy bread	0	0	2	1.2	72	41.7	35	20.2	64	37.0
Sour milk	0	0	2	1.2	30	17.4	27	15.6	114	65.9
Compost heap	0	0	0	0	12	6.9	47	27.2	114	65.9
Sewage works	0	0	1	0.6	22	12.7	26	15.0	124	71.7

Sick child
Advanced statement (score=4)

Category	**Number of responses**	**% response**
The effect of microbial activity in the body	4	2.3

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are the causal agent of disease	22	12.7
Subcategories		
Large numbers are required, breeding	1	0.6
Bad micro-organisms cause disease	2	1.2

Appropriate statement (score=2)

Category	**Number of responses**	**% response**
Microbes are associated with sick child	68	39.3
Subcategories		
Large numbers/ microbes are breeding/spreading	3	1.7
Child has been infected with micro-organisms	8	4.6
Child is infectious /a carrier of micro-organisms	31	17.9
Bad micro-organisms present	1	0.6

Alternative statement no statement /no photograph (score=1)

Category	**Number of responses**	**% response**
Total	35	20.2
Subcategories		
Requires medication	1	0.6

No statement /no photograph (score=0)

Category	**Number of responses**	**% response**
Total	44	25.4

Vaccination
Advanced statement (score=4)

Category	**Number of responses**	**% response**
Micro-organisms (non-pathogenic) used to prevent disease	0	0

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are used in the manufacture of vaccinations	2	1.2

Appropriate statements (score=2)

Category	Number of responses	% response
Vaccine is an anti-microbial / anti-disease agent	14	81.1
Subcategories		
Vaccine used a preventative measure – anti-microbial	6	3.5
Vaccine used a preventative measure – anti-disease	1	0.6
Vaccine used as a curative measure	7	4.0
Associated with sick child	3	1.7

Alternative statement (score=1)

Category	Number of responses	% response
Total	23	13.3
Subcategories		
Physically removes micro-orgs	4	2.3

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	134	77.5

Antibiotics

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms are used in the manufacture of antibiotics	1 (total responses)	0.6

Appropriate statement (score=2)

Category	Number of responses	% response
Antibiotics are anti-microbial / anti-disease agents	17(total responses)	9.8
Subcategories		
Antibiotics used a preventative measure- anti-microbial	5	2.9
Antibiotics as a curative measure –	12	6.9

Alternative statement /no statement /no photograph (score=1)

Category	Number of responses	% response
Total	14	8.1
Subcategories		
Antibiotic resistance// only of prescribed	4	2.3

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	141	81.5

Bleach

Advanced link statement (score=4)

Category	Number of responses	% response
Used to prevent microbial growth	0	0

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Kills micro-organisms – antimicrobial agent	2	1.2

Appropriate statement (score=2)

Category	Number of responses	% response
Acts as a cleansing agent	4	2.3
Subcategories		
Cleans away microbes	1	0.6

Alternative statement (score=1)

Category	Number of responses	% response
Total	35	20.2
Subcategories		
Contains microbes (good ones) to kill others	17	9.8
Dangerous	26	15.0

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	132	76.3

Bread

Advanced statement made (score=4)

Category	Number of responses	% response
Yeast activity used to produce leavened bread	0	0

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Yeast associated with/ in bread	0	0

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated with/in bread	0	0

Alternative statement (score=1)

Category	Number of responses	% response
Alternative statement	3	1.7
Subcategories		
Contaminated	2	1.2

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	170	98.3

Beer

Advanced link made (score=4)

Category	Number of responses	% response
Yeast used in fermentation process	0	0

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Yeast associated with beer production	0	0

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms associated with beer	0	0

Alternative statement (score=1)

Category	Number of responses	% response
Total	28	16.2
Subcategories		
Unhealthy	19	11.0
Contaminated	5	2.9
Microbial presence	9	5.2

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	145	83.8

Yogurt

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms associated with yogurt are bacteria	0	0

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated with yogurt	0	0

Alternative statement (score=1)

Category	Number of responses	% response
Total	7	4.0
Subcategories		
Mouldy/gone off	2	1.2

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	166	96.0

Mouldy bread

Advanced link made (score=4)

Category	Number of responses	% response
Mould as a result of microbial activity/growth	0	0

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms causal factor of mould	2	1.2

Appropriate link (score=2)

Category	Number of responses	% response
Associated with microbial presence	72	41.7
Subcategories		
Bad micro-organisms /negative connotations	3	1.7
Causes illness	43	24.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	35	20.2
Subcategories		
Gone off	12	6.9
Dirty/unpleasant	11	6.4

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	64	47.0

Sour milk

Advanced statement (score=4)

Category	Number of responses	% response
Sour as a result of microbial activity/growth	0	0

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Microbial causation	2	1.2

Appropriate statement (score=2)

Category	Number of responses	% response
Associated with microbial presence	30	17.4
Subcategories		
Bad micro-organisms/ negative connotations	3	1.7
Cause illness	20	11.6

Alternative statement (score=1)

Category	Number of responses	% response
Total	27	15.6
Subcategories		
Gone off	14	8.1
Dirty/unpleasant	4	2.3

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	114	65.9

Compost heap

Advanced link made (score=4)

Category	Number of responses	% response
Micro-organisms cause decay and the products are recycled	0	0

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms cause decay	0	0

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms present in compost heap	12	6.9
Subcategories		
Linked to dirt/rubbish	2	1.2

Alternative statement (score=1)

Category	Number of responses	% response
Total	47	27.2
Subcategories		
Dirty/unpleasant connotations	15	8.7
Risk of contamination	32	18.5

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	114	65.9

Sewage works

Advanced statement (score=4)

Category	Number of responses	% response
Micro-organisms clean up the water/break down waste products	0	0

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms removed/waste products removed	1	0.6

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated/present	22	12.7
Subcategories		
Excreta from humans present	9	5.2
Linked to dirt/rubbish negative connotations	3	1.7

Alternative statement (score=1)

Category	Number of responses	% response
Total	26	15.0
Subcategories		
Dirty/unpleasant connotations	12	6.9
Risk of contamination	13	7.5

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	124	71.7

Appendix 4b

Summary data: Year 6 photograph association concept maps
N=169

Photograph	Total Score =4	%	Total Score =3	%	Total Score =2	%	Total Score =1	%	Total Score =0	%
Sick child	4	2.4	60	35.5	41	24.3	12	7.1	52	30.8
Vaccination	2	1.2	26	15.4	64	37.9	12	7.1	65	28.5
Antibiotics	0	0	32	18.9	66	39.1	10	5.9	61	36.1
Bleach	1	0.6	27	16.0	9	5.3	40	23.7	92	54.4
Bread	2	1.2	17	10.1	15	8.9	24	14.2	111	65.7
Beer	2	1.2	18	10.7	23	13.6	33	19.5	93	55.0
Yogurt	0	0	4	2.4	40	23.7	35	20.7	93	55.0
Mouldy bread	7	4.1	49	29.0	47	27.8	22	13.0	44	26.0
Sour milk	2	1.2	32	18.9	40	23.7	31	18.3	64	37.9
Compost heap	2	1.2	13	7.7	22	13.0	26	15.4	106	62.7
Sewage works	2	1.2	6	3.6	44	26.0	28	16.6	89	52.7

Sick child
Advanced statement (score=4)

Category	**Number of responses**	**% response**
The effect of microbial activity in the body	4	2.4

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are the causal agent of disease	60	35.5
Subcategories		
Large numbers are required, breeding	3	1.8
Bad micro-organisms cause disease	11	6.5

Appropriate statement (score=2)

Category	**Number of responses**	**% response**
Microbes are associated with sick child	41	24.3
Subcategories		
Large numbers/ microbes are breeding/spreading	10	5.9
Child has been infected with micro-organisms	5	3.0
Child is infectious /a carrier of micro-organisms	6	3.6
Bad micro-organisms present	8	4.7
Deadly	2	1.2

Alternative statement no statement /no photograph (score=1)

Category	**Number of responses**	**% response**
Total	12	7.1

No statement /no photograph (score=0)

Category	**Number of responses**	**% response**
Total	52	30.8

Vaccination
Advanced statement (score=4)

Category	**Number of responses**	**% response**
Micro-organisms (non-pathogenic) used to prevent disease	2	1.2

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are used in the manufacture of vaccinations	26	15.4
Subcategories		
Micro- organisms are beneficial	16	9.5
Micro-organisms used as a preventative measure	10	5.9
Micro-organisms used as a curative measure	10	5.9
Vaccine and antibiotics are the same/similar	7	4.1

Appropriate statements (score=2)

Category	Number of responses	% response
Vaccine is an anti-microbial / anti-disease agent	64	37.9
Subcategories		
Vaccine used a preventative measure – anti-microbial	32	18.9
Vaccine used a preventative measure – anti-disease	18	10.7
Vaccine used as a curative measure	20	11.8
Associated with sick child	18	10.7
Associated with antibiotics and bleach	15	8.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	12	7.1

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	65	28.5

Antibiotics

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms are used in the manufacture of antibiotics	32	18.9
Subcategories		
Micro- organisms are beneficial	22	13.0
Antibiotics used as a preventative measure	6	3.6
Antibiotics used as a curative measure	17	10.1
Vaccine and antibiotics are the same/similar	7	4.1
Link to sick child	3	1.8

Appropriate statement (score=2)

Category	Number of responses	% response
Antibiotics are anti-microbial / anti-disease agents	66	39.1
Subcategories		
Antibiotics used a preventative measure- anti-microbial	30	17.8
Antibiotics as a curative measure - antimicrobial	6	3.6
Antibiotics as a curative measure – anti-disease	34	20.1
Associated with sick child	23	13.6
Associated with antibiotics and bleach	15	8.9

Alternative statement /no statement /no photograph (score=1)

Category	Number of responses	% response
Total	10	5.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	61	36.1

Bleach

Advanced link statement (score=4)

Category	Number of responses	% response
Used to prevent microbial growth	1	0.6

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Kills micro-organisms – antimicrobial agent	27	16.0
Subcategories		
Kills harmful microbes	4	2.4
Antimicrobial with links to antibiotics and vaccine	10	5.9

Appropriate statement (score=2)

Category	Number of responses	% response
Acts as a cleansing agent	9	5.3
Subcategories		
Cleans away microbes	3	1.8

Alternative statement (score=1)

Category	Number of responses	% response
Total	40	23.7
Subcategories		
Contains microbes (good ones) to kill others	27	16.0
Dangerous	8	4.7

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	92	54.4

Bread

Advanced statement made (score=4)

Category	Number of responses	% response
Yeast activity used to produce leavened bread	2	1.2

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Yeast associated with/ in bread	17	10.1
Subcategories		
Yeast is a type of micro-organism	11	6.5
Yeast is used in manufacture of bread	10	5.9
Associations with other food products	8	4.7

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated with/in bread	15	8.9
Subcategories		
Micro-organisms used in manufacture of bread	10	5.9
Associations with other food products	5	3.0

Alternative statement (score=1)

Category	Number of responses	% response
Alternative statement	24	14.2

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	111	65.7

Beer

Advanced link made (score=4)

Category	Number of responses	% response
Yeast used in fermentation process	2	1.2

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Yeast associated with beer production	18	10.7
Subcategories		
Yeast used in manufacture of beer	12	7.1
Yeast is a type of microbe	7	4.1
Association with other food products	12	7.1

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms associated with beer	23	13.6
Subcategories		
Micro-organisms used to produce beer	20	11.8
Association with other food products	6	3.6

Alternative statement (score=1)

Category	Number of responses	% response
Total	33	19.5
Subcategories		
Unhealthy	15	8.9
Contaminated	11	6.5
Microbial presence	12	7.1

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	93	55.0

Yogurt

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms associated with yogurt are bacteria	4)	2.4

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated with yogurt	40	23.7
Subcategories		
Micro-organisms used to make yogurt	24	14.2
Beneficial micro-organisms present in yogurt	15	8.9
Associated with other food products	8	4.7

Alternative statement (score=1)

Category	Number of responses	% response
Total	35	20.7
Subcategories		
Yeast used	11	6.5
Mouldy/gone off	7	4.1
Contaminated	6	3.6

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	93	55.0

Mouldy bread

Advanced link made (score=4)

Category	Number of responses	% response
Mould as a result of microbial activity/growth	7 (total responses)	4.1

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms causal factor of mould	49 (total responses)	29.0
Subcategories		
Mould is a type of microbe	5	3.0
Old/left out	4	2.4
Links(e.g. sour milk)	3	1.8

Appropriate link (score=2)

Category	Number of responses	% response
Associated with microbial presence	47	27.8
Subcategories		
Bad micro-organisms /negative connotations	10	5.9
Causes illness	18	10.7

Alternative statement (score=1)

Category	Number of responses	% response

Total	22	13.0
Subcategories		
Gone off	14	8.3

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	44	26.0

Sour milk

Advanced statement (score=4)

Category	Number of responses	% response
Sour as a result of microbial activity/growth	2	1.2

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Microbial causation	32	18.9
Subcategories		
Old	2	1.2
Bad	1	0.6
Links	5	3.0
Contamination	5	3.0

Appropriate statement (score=2)

Category	Number of responses	% response
Associated with microbial presence	40	23.7
Subcategories		
Bad micro-organisms/ negative connotations	6	3.6
Cause illness	15	8.9
Links	3	1.8

Alternative statement (score=1)

Category	Number of responses	% response
Total	31	18.3
Subcategories		
Gone off	14	8.3

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	64	37.9

Compost heap

Advanced link made (score=4)

Category	Number of responses	% response
Micro-organisms cause decay and the products are recycled	2	1.2

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms cause decay	13	7.7

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms present in compost heap	22	13.0
Subcategories		
Linked to dirt/rubbish	9	5.3

Alternative statement (score=1)

Category	Number of responses	% response
Total	26	15.4
Subcategories		
Dirty/unpleasant connotations	12	7.1

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	106	62.7

Sewage works

Advanced statement (score=4)

Category	Number of responses	% response
Micro-organisms clean up the water	2	1.2

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro organism break down waste products/micro-organisms removed	6	3.6

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated/present	44	26.0
Subcategories		
Excreta from humans present	14	8.3
Linked to dirt/rubbish negative connotations	6	3.6

Alternative statement /no statement /no photograph (score=0)

Category	Number of responses	% response
Total	28	16.6
Subcategories		
Dirty/unpleasant connotations	17	10.1

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	89	52.7

Appendix 4b

Summary data: Year 9 photograph association concept maps
N=103

Photograph	Total Score =4	%	Total Score =3	%	Total Score =2	%	Total Score =1	%	Total Score =0	%
Sick child	1	0.9	22	21.4	25	24.3	11	10.7	44	42.7
Vaccination	5	4.9	15	14.6	45	43.7	5	4.9	33	32.0
Antibiotics	0	0	8	7.8	51	49.5	13	12.6	31	30.1
Bleach	0	0	46	44.7	3	2.9	11	10.7	43	41.7
Bread	3	2.9	30	29.1	5	4.9	11	10.7	54	52.4
Beer	1	0.9	31	30.1	7	6.8	11	10.7	53	51.5
Yogurt	1	0.9	5	4.9	16	15.5	27	26.2	54	52.4
Mouldy bread	0	0	19	18.4	21	20.4	22	21.4	41	39.8
Sour milk	0	0	13	12.6	13	12.6	25	24.3	52	50.5
Compost heap	2	1.9	13	12.6	15	14.6	19	18.4	54	52.4
Sewage works	1	0.9	9	8.7	20	19.4	18	17.5	55	53.4

Sick child
Advanced statement (score=4)

Category	**Number of responses**	**% response**
The effect of microbial activity in the body	1	0.9

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are the causal agent of disease	22	21.4

Appropriate statement (score=2)

Category	**Number of responses**	**% response**
Microbes are associated with sick child	25	24.3
Subcategories		
Large numbers/ microbes are breeding/spreading	1	0.9
Child has been infected with micro-organisms	12	11.7
Child is infectious /a carrier of micro-organisms	4	3.9

Alternative statement no statement /no photograph (score=1)

Category	**Number of responses**	**% response**
Total	11	10.7
Subcategory		
Medication required	8	7.8

No statement /no photograph (score=0)

Category	**Number of responses**	**% response**
Total	44	42.7

Vaccination
Advanced statement (score=4)

Category	**Number of responses**	**% response**
Micro-organisms (non-pathogenic) used to prevent disease	5	4.9

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Micro-organisms are used in the manufacture of vaccinations	15	14.6
Subcategories		
Micro- organisms are beneficial	2	1.9
Micro-organisms used as a preventative measure	5	4.9
Vaccine and antibiotics are the same/similar	1	0.9

Appropriate statements (score=2)

Category	Number of responses	% response
Vaccine is an anti-microbial / anti-disease agent	45	43.7
Subcategories		
Vaccine used a preventative measure – anti-microbial	18	17.5
Vaccine used a preventative measure – anti-disease	16	15.5
Vaccine used as a curative measure	10	9.7
Associated with sick child	17	16.5
Associated with antibiotics and bleach	10	9.7

Alternative statement (score=1)

Category	Number of responses	% response
Total	5	4.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	33	32.0

Antibiotics

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms are used in the manufacture of antibiotics	8	7.8
Subcategories		
Micro- organisms are beneficial	1	0.9
Antibiotics used as a preventative measure	1	0.9
Antibiotics used as a curative measure	1	0.9

Appropriate statement (score=2)

Category	Number of responses	% response
Antibiotics are anti-microbial / anti-disease agents	51	49.5
Subcategories		
Antibiotics used a preventative measure- anti-microbial	27	26.2
Antibiotics used a preventative measure- anti-disease	5	4.9
Antibiotics as a curative measure – antimicrobial / Antibiotics as a curative measure - anti-disease	21	20.4
Associated with sick child	17	16.5
Associated with antibiotics and bleach	19	18.4

Alternative statement /no statement /no photograph (score=1)

Category	Number of responses	% response
Total	13	12.6
Subcategories		
antiviral	5	4.9
antibodies	3	2.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	31	30.1

Bleach

Advanced link statement (score=4)

Category	Number of responses	% response
Used to prevent microbial growth	0	0

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Kills micro-organisms – antimicrobial agent	46	**44.7**
Subcategories		
Antimicrobial with links to antibiotics and vaccine	3	2.9

Appropriate statement (score=2)

Category	**Number of responses**	**% response**
Acts as a cleansing agent	3	2.9

Alternative statement (score=1)

Category	**Number of responses**	**% response**
Total	11	10.7
Subcategories		
Contains microbes	3	2.9
Dangerous	1	0.9

No statement /no photograph (score=0) **Category**	**Number of responses**	**% response**
Total	43	41.7

Bread
Advanced statement made (score=4)

Category	**Number of responses**	**% response**
Yeast activity used to produce leavened bread	3	2.9

Accurate /Detailed statement (score=3)

Category	**Number of responses**	**% response**
Yeast associated with/in b read	30	29.1
Subcategories		
Yeast is a type of micro-organism	4	3.9
Yeast is used in manufacture of bread	7	6.8
Associations with other food products	21	20.4

Appropriate statement (score=2)

Category	**Number of responses**	**% response**
Micro-organisms associated with/in bread	5	4.9
Subcategories		
Micro-organisms used in manufacture of bread	1	0.9

Alternative statement (score=1)

Category	**Number of responses**	**% response**
Alternative statement	11	10.7
Subcategories		
Fresh	3	2.9
Contaminated	6	5.8

No statement /no photograph (score=0)

Category	**Number of responses**	**% response**
Total	54	52.4

Beer
Advanced link made (score=4)

Category	**Number of responses**	**% response**
Yeast used in fermentation process	1	0.9

Accurate /Detailed link (score=3)

Category	**Number of responses**	**% response**
Yeast associated with beer production	31	30.1
Subcategories		
Yeast used in manufacture of beer	10	9.7
Yeast is a type of microbe	4	3.9
Association with other food products	21	20.4

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms associated with beer	7	6.8
Subcategories		
Micro-organisms used to produce beer	3	2.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	11	10.7
Subcategories		
Unhealthy	3	2.9
Contaminated	4	3.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	53	51.5

Yogurt

Advanced link made (score=4)

Category	Number of responses	% response
Bacterial/ microbial culture, affect on milk	1	0.9

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms associated with yogurt are bacteria	5	4.9

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated with yogurt	16	15.5
Subcategories		
Micro-organisms used to make yogurt	5	4.9
Beneficial micro-organisms present in yogurt	4	3.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	27	26.2
Subcategories		
Yeast used	1	0.9
Mouldy/gone off	21	20.4
Contaminated	1	0.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	54	52.4

Mouldy bread

Advanced link made (score=4)

Category	Number of responses	% response
Mould as a result of microbial activity/growth	0	0

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms causal factor of mould	19	18.4
Subcategories		
Mould is a type of microbe	1	0.9

Appropriate link (score=2)

Category	Number of responses	% response
Associated with microbial presence	21	20.1
Subcategories		
Bad micro-organisms /negative connotations	1	0.9
Causes illness	3	2.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	22	21.4
Subcategories		
Gone off	8	7.8

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	41	39.8

Sour milk

Advanced statement (score=4)

Category	Number of responses	% response
Sour as a result of microbial activity/growth	0	0

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Microbial causation	13	12.6
Subcategories		
Old	1	0.9

Appropriate statement (score=2)

Category	Number of responses	% response
Associated with microbial presence	13	12.6
Subcategories		
Cause illness	4	3.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	25	24.3
Subcategories		
Gone off	8	7.8
Dirty/unpleasant	2	1.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	52	50.5

Compost heap

Advanced link made (score=4)

Category	Number of responses	% response
Micro-organisms cause decay and the products are recycled	2	1.9

Accurate /Detailed link (score=3)

Category	Number of responses	% response
Micro-organisms cause decay	13	12.6

Appropriate link (score=2)

Category	Number of responses	% response
Micro-organisms present in compost heap	15	14.6
Subcategories		
Linked to dirt/rubbish	1	0.9

Alternative statement (score=1)

Category	Number of responses	% response
Total	19	18.4
Subcategories		
Dirty/unpleasant connotations	3	2.9
Risk of contamination	5	4.9

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	54	52.4

Sewage works

Advanced statement (score=4)

Category	Number of responses	% response
Micro-organisms clean up the water/ break down waste products	1	0.9

Accurate /Detailed statement (score=3)

Category	Number of responses	% response
Micro-organisms removed/waste products removed	9	8.7

Appropriate statement (score=2)

Category	Number of responses	% response
Micro-organisms associated/present	20	19.4
Subcategories		
Excreta from humans present	2	1.9
Linked to dirt/rubbish negative connotations	1	0.9

Alternative statement /no statement /no photograph (score=0)

Category	Number of responses	% response
Total	18	17.5
Subcategories		
Dirty/unpleasant connotations	8	7.8

No statement /no photograph (score=0)

Category	Number of responses	% response
Total	55	53.4

Appendix 4c

Year 2: Concept map responses to photograph of sick child

Code name	Sorting code	Comment sick child
tb10	0	
tb11	0	
tb17	0	
tb23	0	
tb24	0	
tb25	0	
tb31	0	
si4	0	
si10	0	
si15	0	
si24	0	
si41	0	
si45	0	
si47	0	
hai1	0	
hai2	0	
hai5	0	
hai8	0	
hai10	0	
hai11	0	
hai13	0	
hai17	0	
hai20	0	
hai22	0	
hai23	0	
hai24	0	
hai28	0	
hai30	0	
hai31	0	

hai32	0	
hai35	0	
hai36	0	
hai38	0	
hai44	0	
hai50	0	
hai52	0	
hai60	0	
hai62	0	
hai63	0	
hai67	0	
hai71	0	
hai73	0	
hai77	0	
hai79	0	
tb1	1	bad
tb7	1	being sick means germs
tb15	1	bad
tb18	1	when the baby is sick it must go to the hospital
tb26	1	because he has brown spots and is disgusting
tb28	1	the baby is ill
tb30	1	if you are sick you don't feel well
tb35	1	because he's been sick
tb39	1	if you're poorly you might be sick
tb40	1	spots, sick
tb42	1	spots
si6	1	he has got spots
si11	1	a sick baby
si14	1	a sick baby
si17	1	he has a rash
si19	1	because he's sick
si20	1	the child is poorly
si25	1	this baby is sick

si28	1	the baby got sick because it ate something
si30	1	because he has gone orange
si31	1	the little orange spots have something to do with germs
si32b	1	it has something wrong with it
si33	1	because it is ill and got this stuff on it
si36	1	because he has spots all over him
si40	1	it is a sick baby, he has got chicken pox
si43	1	because he has orange spots
si49	1	because he has a very bad rash
hai3	1	I think sick is germs
hai16	1	because he has red dots on him
hai25	1	he's got chicken pox
hai42	1	when you get the chicken pox it is called a germ
hai51	1	because spots have germs on
hai53	1	chicken pox
hai68	1	I think the spots are germs
hai70	1	he's not well
tb3	2	because he's got chicken pox and that's germs
tb8	2	have germs in them
tb9	2	when it is sick it releases germs
tb13	2	because sick (child) is germy
tb16	2	germs live in sick
tb27	2	the germs have come out of his body
tb32	2	the germs come out of the child
tb37	2	the child has germs because it has spots
tb38	2	because it (the child) gets your spots
tb43	2	the baby has spots and got germs
tb45	2	the baby has germs on his body
si37	2	he has a germ inside his body
si39	2	this child has germs inside him
si48	2	I think it is germs, it is chicken pox
hai4	2	if you are ill you have germs
hai19	2	he's got a germ called chicken pox

hai26	2	has germs
hai29	2	sick has germs in it
hai45	2	it looks like its got germs
hai46	2	because the baby has a germ inside her body
hai47	2	the baby has germs
hai49	2	it has germs because it is poorly
hai64	2	a sick child because sick has germs
hai69	2	he has a germ
hai78	2	this has germs
tb2	2	I know a sick child is bad because you could catch his germs
tb4	2	a sick child can make you catch germs
tb5	2	the baby is ill, you must keep away or you will catch germs
tb6	2	all spotty these are germs , you might catch it
tb19	2	if you go too close you might get sick
tb20	2	its got all sick on it, makes you have a bug
tb22	2	if the child's brother comes near him he will have chicken pox too, I know because I had it and my brother caught it
tb29	2	because the sick has come out of her mouth and you could catch diseases and germs
tb33	2	you might catch the disease and germs
tb34	2	if you touch it you get really sick
tb44	2	if you go near the baby you will catch germs
si2	2	you could get germs from the baby if you get near it
si3	2	this is germs because he can pass it on
si18	2	the child might pass germs on
si21	2	this child is sick and it could spread
si34	2	I think this is germs because he could pass it on to another person and they would get sick
si35	2	you could get germs from the baby if you get near it
si42	2	it can make you sick
si44	2	the sick child might pass on germs to another child
si46	2	this baby is ill so if you go too close to him he will make you ill
hai15	2	it can jump from person to person
hai18	2	if you go near someone who is sick you might get germs as well
hai33	2	has germs because somehow you can catch the germs off them
hai34	2	this is bad for you because you might catch it off him

hai39	2	when you go near someone you can get germs from them
hai40	2	it's a bit like nits they (germs) jump from one person to another
hai41	2	you could catch the sickness off the baby
hai54	2	I think a sick child is not good because you could catch it
hai59	2	when you're sick the germs will spread all over you
hai61	2	the sick child has germs that can spread to me or you
hai66	2	I think this has something to do with germs because you catch it from somebody
tb36	2	the baby has got germs because they got on him
tb41	2	got germs
si12	2	this baby must be ill because germs have got into his mouth
si29	2	the baby is sick and has caught germs, chicken pox or shingles from somebody
si32a	2	germs have crept in her body
hai12	2	swallowed a germ
hai55	2	this is a germ because the child could have eaten something bad
hai80	2	a sick child could have caught a germ at home
tb14	2	baby has millions of tiny germs
hai14	2	when you are sick you have lots of germs
hai56	2	lots of germs
tb21	2	bad germ
hai37	3	because of chicken pox or germs
hai9	3	because the baby had germs
hai75	3	because germs are diseases and they growed in there
hai76	3	the baby has germs because he is sick
tb47	3	if you go near the sick child you could catch it, germs are horrible they give you a very very bad tummy
si1	3	because germs make you sick
si5	3	this is how he got sick, the boy has germs
si8	3	because the germs went through the body
si9	3	because germs make you sick and this baby is sick
si13	3	because germs make you feel sick
si16	3	the germs have made this boy ill
si22	3	germs make you sick
si27	3	the baby is poorly because of germs
si38	3	the child has got hit by germs and is poorly

hai6	3	a sick child has germs because how the child got sick is because a bug got into his tummy
hai7	3	because you get sick from a germ, sick is a germ
hai27	3	the baby is poorly because the germs are bad
hai58	3	this is a germ because you get ill when you have a germ and this baby is ill
hai74	3	baby's normally get sickness from different germs
hai57	3	the child ate some really bad germs
hai72	3	germs make you ill because they are bad things
si26	3	sick because it has many germs
si23	4	the baby has got spots because it has germs
hai21	4	he's sick, the germs aren't doing very well to him, some germs can be nasty
hai43	4	this is a germ because he has red spots all over him because he has germs
hai65	4	a sick child has a germ because it has a very red rash

Appendix 4c

Year 6: Concept map responses to photograph of sick child

Code name	Sorting code	Comment sick child
sj28	0	
sj46	0	
sj57	0	
haj2	0	
haj5	0	
haj6	0	
haj9	0	
haj16	0	
sm3	0	
sm32	0	
sj8	0	
haj18	0	
haj21	0	
haj24	0	
haj26	0	
haj27	0	
haj34	0	
haj49	0	
haj53	0	
haj59	0	
haj64	0	
haj67	0	
haj74	0	
haj78	0	
sm4	0	
sm8	0	
sm10	0	

sm11	0	
sm14	0	
sm16	0	
sm21	0	
sm28	0	
sm29	0	
sm30	0	
sm31	0	
sm34	0	
sm36	0	
sj19	0	
sj40	0	
haj13	0	
haj20	0	
haj36	0	
haj51	0	
haj70	0	
haj75	0	
sj49	0	
sm19	0	
sj32	0	
sj51	0	
sm27	0	
sj45	0	
sj5	0	
sj11	1	very bad
sj18	1	to do with micro-organisms
sj20	1	this is a type of microbe that is bad -link to sour milk
sj27	1	this illness that the baby has is germs
sj35	1	this baby is ill so he needs to take antibiotics or a vaccination like the girl
sj38	1	the child is ill

haj1	1	mouldy
haj76	1	diseases have lots of germs on them
sj15	1	because he is sick
sj52	2	has germs
haj11	2	because it has micro-organisms
haj25	2	because it has micro-organisms
sm20	2	has germs
sj7	2	more germs than microbes
sj12	2	prevention of microbes stops sickness
sm15	2	sick child has a disease with micro-organisms inside him
sm2	2	sick child has germs
sm26	2	there are micro-organisms because it has got a disease and a strong illness
haj7	2	carries germs
haj29	2	carries germs
haj14	2	because the child carries germs
haj45	2	carries germs, it's also got a virus
haj30	2	the child carry's germs
haj60	2	because when you sick you can catch it
haj4	2	dangerous to go near
sj30	2	sick child can make you sick
haj61	2	the baby is full of bad germs
haj71	2	full of germs
sj55	2	germs breed
sj6	2	germs breed; because you can catch microbes when your sick
sj39	2	germs spread over child
sj50	2	he's congested in microbes
haj19	2	it is infested with micro-organisms
haj73	2	spreadable micro-organisms
sj43	2	spreading germs
haj44	2	I chose a sick child because micro-organisms breed in hot places and bad germs can breed quickly
sm33	2	because picked up something with micro-organisms in it

sj23	2	because the child could have caught the germs
haj79	2	eating bad things with micro-organisms
sj17	2	microbes infect his skin
sm12	2	has been infected by a disease
sm13	2	it caught the disease
sj26	2	because he has got chicken pox
haj56	2	because it wasn't protected from bad germs
sj31	2	babies can carry lots of germs when sick
haj8	2	bad micro-organisms
sj54	2	because they have bad germs
haj17	2	bad bacteria
haj33	2	bad germs on the boy
sm17	2	sick child must be allergic to something, he's got bad bacteria all over him
haj69	2	I think this child has eaten bad micro-organisms
haj31	2	deadly
haj58	2	death
sj14	3	diseases are made from germs
sj29	3	diseases are made from germs
sj24	3	because germs make you sick
sj1	3	because has got an illness called chicken pox which are created by microbes
haj22	3	because micro-organisms cause sickness
sj2	3	because micro-organisms cause diseases
haj72	3	because of germs
haj39	3	because of micro-organisms
haj40	3	because of micro-organisms
haj41	3	because of micro-organisms
haj43	3	because of micro-organisms
haj47	3	because of micro-organisms
haj48	3	because of micro-organisms
haj50	3	because of micro-organisms
haj77	3	because of micro-organisms

sm1	3	can cause diseases
haj23	3	can cause illness
haj32	3	can cause sickness
haj55	3	cause sickness that is why the baby has spots
sj4	3	caused by microbes
haj38	3	caused by micro-organisms
haj35	3	causes illness
haj57	3	causes illness
haj54	3	causes sickness
sj47	3	germs get inside us and make us ill so that's why we must be careful
haj66	3	germs made child sick
sm39	3	germs make you sick
sj22	3	it has been made ill by microbes
sj48	3	made ill (by germs)
haj62	3	made ill by micro-organisms and ended up with germs
sj21	3	microbes make you sick and he is a sick child
haj3	3	micro-organisms (evolve into bugs) can cause sick child - leads to death
sm5	3	micro-organisms can make you sick
haj52	3	micro-organisms cause illness
haj65	3	micro-organisms causes diseases
haj46	3	micro-organisms causes illness
sm35	3	micro-organisms made her get ill
sm22	3	micro-organisms made the child ill
sm24	3	micro-organisms makes him sick
haj15	3	sick because of micro-organisms
haj10	3	sick child because of micro-organisms
sj37	3	the baby's sick because of micro-organisms
haj28	3	the organisms cause him to be sick
sm7	3	this baby contains bad micro-organisms to make him unwell
haj63	3	because of germs
sj3	3	caused by micro-orgs

sj9	3	microbes cause sickness
sj13	3	sick children are sometimes made sick by microbes
sm18	3	the micro-organisms in the body caused the baby to be ill
sm38	3	bad micro-organisms are making the child sick and the micro-organisms are so small you or anyone else can't see them
haj68	3	because of bad micro-organisms
haj37	3	causes illness this is down to the bad micro-organisms
haj42	3	gets sick because had bad germs/micro-organisms
sj42	3	harmful micro-organisms have made the baby ill
sm23	3	micro-organisms because its made the baby ill and its bad micro-organisms
haj12	3	sick because of bad micro-organisms
sj10	3	has a bad microbe that made him ill
sj33	3	because something must have caused the disease. I think it was a bad micro-organisms
sj36	3	bacteria has infected (taken over) the child's body
sm25	3	there are many bad micro-organism in the child causing it to be sick
sj44	4	germs and microbes have spread around his body and made him ill
sj53	4	the after effect of bad germs
sm37	4	the micro-organisms have done something to the child to make them ill
sm6	4	this is the outcome of germs

Appendix 4c

Year 9: Concept map responses to photograph of sick child

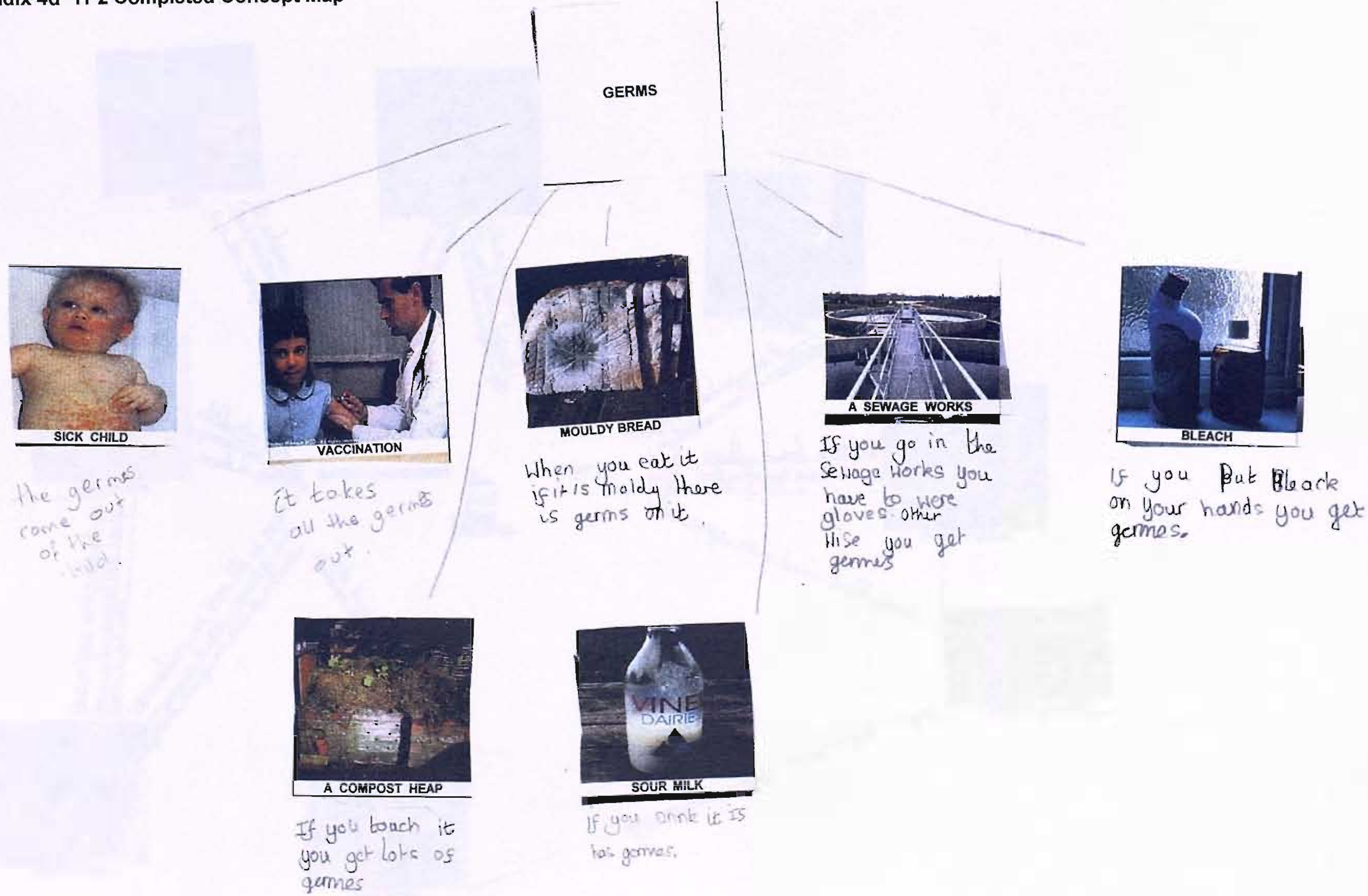
Code name	Sorting code	Comment sick child
ca4	0	
ca6	0	
ca17	0	
ca20	0	
ca22	0	
ca23	0	
ca24	0	
ca25	0	
ca28	0	
ca30	0	
ca32	0	
ca39	0	
ca41	0	
ca42	0	
ca46	0	
ca47	0	
ca48	0	
ca52	0	
ca55	0	
ca56	0	
ca57	0	
ca59	0	
ca60	0	
ca61	0	
ca66	0	
ca68	0	
ca69	0	
ca70	0	
ca71	0	

ca72	0	
ca73	0	
ca75	0	
ca78	0	
ca79	0	
ca82	0	
ca87	0	
ca91	0	
ca92	0	
ca93	0	
ca97	0	
ca101	0	
ca102	0	
ca104	0	
ca107	0	
ca8	1	ill - link to vaccination and antibiotics- you can get better with the medicine
ca21	1	did not get a vaccination
ca44	1	causes germs
ca45	1	germs
ca49	1	the child was not vaccinated against disease
ca53	1	when a baby is born if its mother is not protected against certain diseases then the baby isn't
ca63	1	sick child needs help - link to vaccination
ca105	1	ill- link to vaccination and antibiotics
ca110	1	bad for you
ca77	1	you can get ill - link to vaccination, can't fight bacteria
ca88	1	did not get a vaccination
ca1	2	could be contagious
ca5	2	a sick child is infected with germs
ca7	2	is infected by germs- link to antibiotics and bleach
ca9	2	virus
ca10	2	attacked by germs - link to antibiotics (needs to have them)
ca13	2	a virus
ac14	2	infected with germs

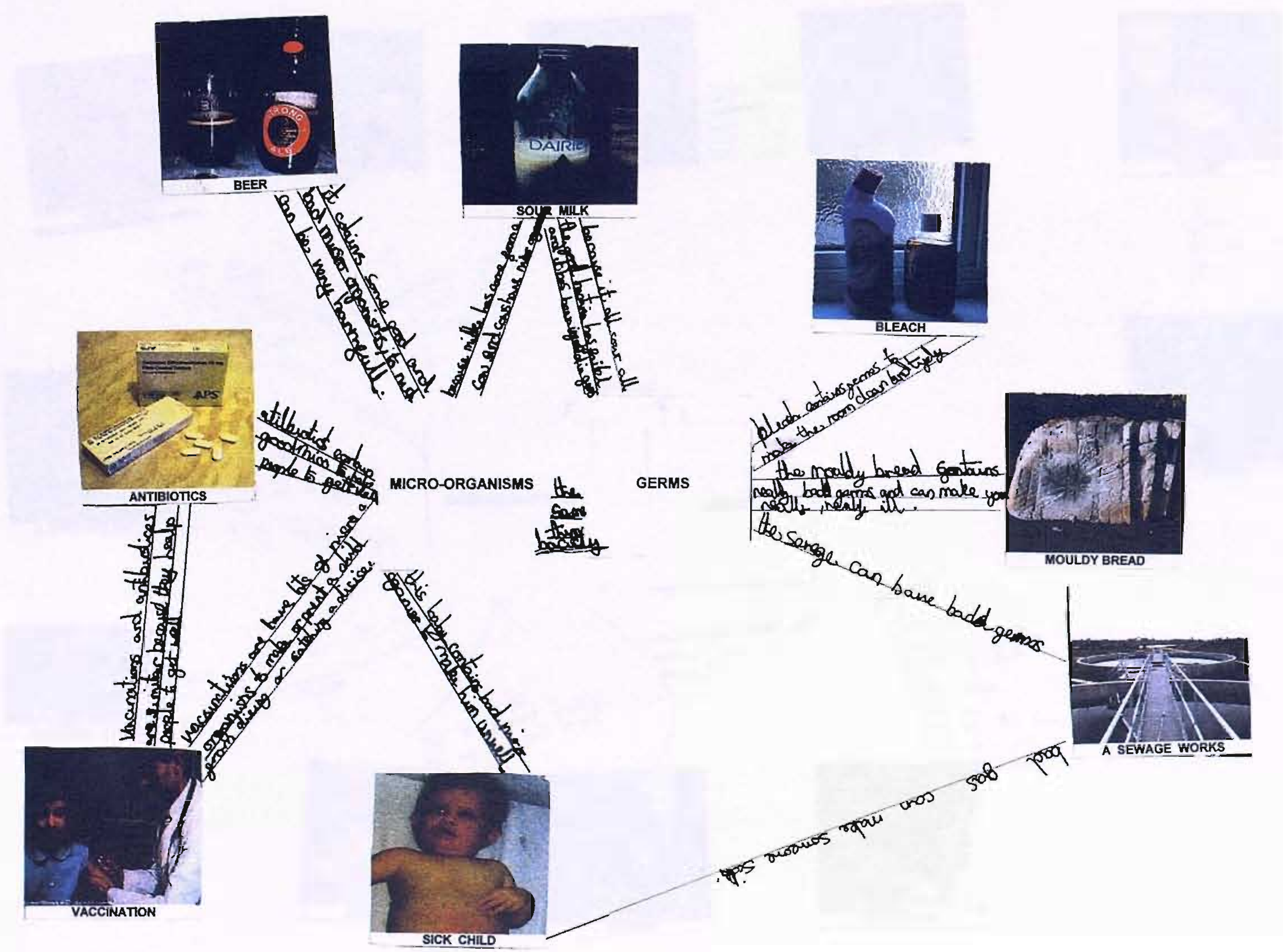
ca16	2	micro-orgs are eating him
ca18	2	germs infect the child
ca27	2	the child might be ill from germs or full of micro-organisms
ca31	2	infected
ca33	2	germs breed on sick children
ca34	2	too many germs
ca40	2	there are micro-organisms in a sick child
ca43	2	germs infected the child
ca50	2	infected (with germs)
ca62	2	germs
ca64	2	has germs in
ca67	2	caught germs
ca95	2	both have germs and micro-organisms in them (link to vaccination)
ca96	2	carries germs
ca99	2	germs invade the child's body
ca103	2	carries germs
ca108	2	contains germs that will make you ill
ca109	2	caught a germ
ca2	3	makes child ill
ca3	3	micro-organisms give this child its sickness
ca11	3	germs make kids sick (link to vaccination) when children get sick they need vaccinations
ca12	3	the micro-organisms get into the blood and make the child sick
ca15	3	germs make the child sick
ca19	3	germs make baby ill link to antibiotics
ca37	3	germs make the child sick
ca38	3	germs cause disease
ca51	3	germs cause sickness
ca54	3	makes child ill
ca58	3	germs make child ill
ca65	3	germs make the child ill
ca74	3	germs makes the child ill
ca76	3	germs cause this
ca80	3	micro-organisms/germs causes this

ca84	3	the germs on this child has made it sick
ca85	3	germs can cause child to be very ill
ca86	3	germs makes the child sick
ca89	3	the germs in the child has made the child ill
ca90	3	the bacteria and germs which is micro-organisms is making the baby sick
ca94	3	baby's get ill over bad germs
ca106	3	ill from germs
ca35	4	germs have got into his body and affected his skin

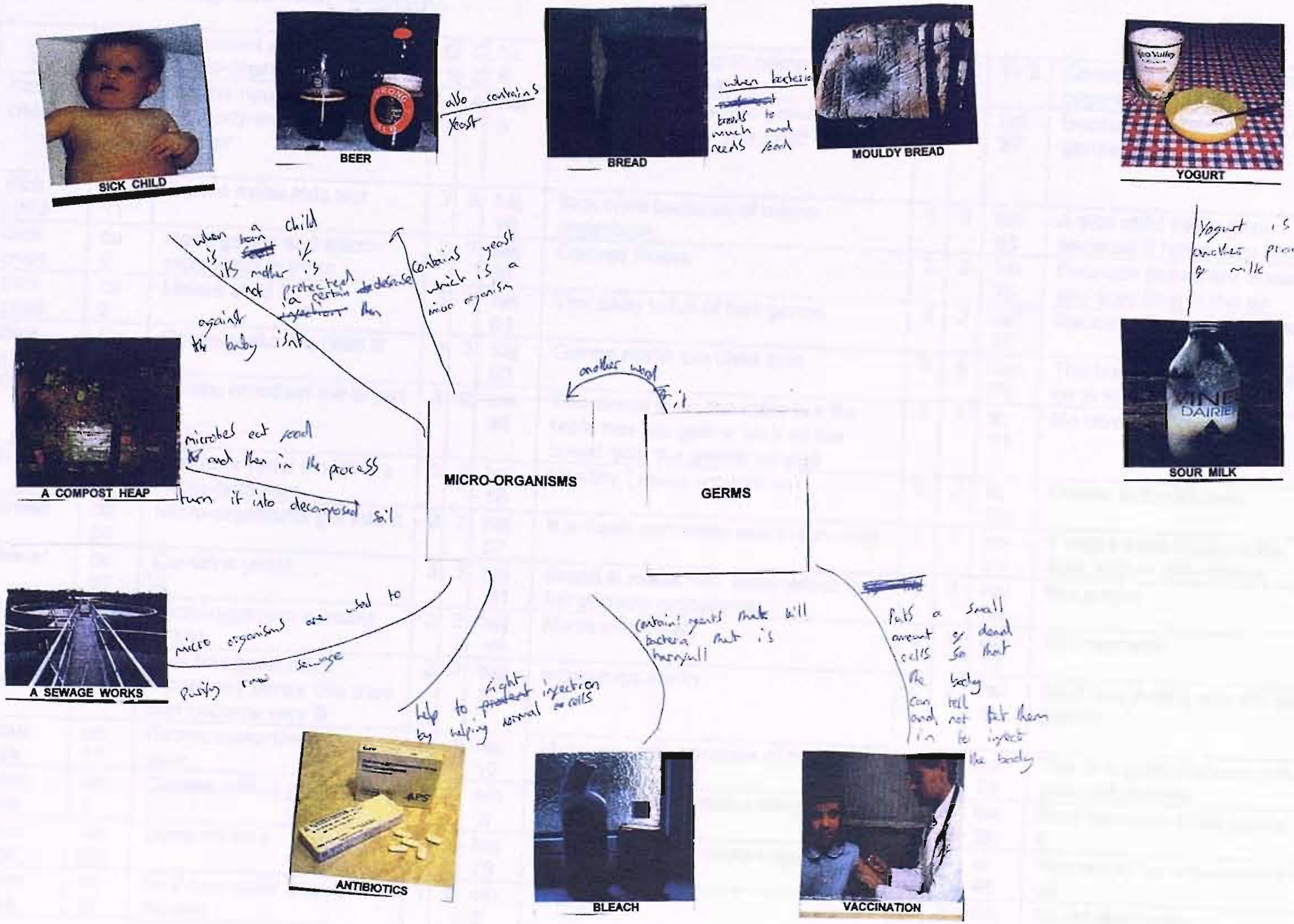
Appendix 4d Yr 2 Completed Concept Map



Appendix 4d Yr 6 Completed Concept Map



Appendix 4d Yr 9 Completed Concept Map



Appendix 5

Concept map coding: inter-rater reliability

	Yr 9	Comment related to micro-organisms/germs	C 1	C 2	Yr 6	Comment related to micro-organisms/germs	C 1	C 2	Yr 2	Comment related to micro-organisms/germs	C 1	C 2
Sick child	ca 35	Germs have gotten into his body and affected his/her skin	4	4	haj 3	has micro-organisms (evolve into bugs) can cause sick child - leads to death	3	3	hai 37	Because of chicken pox or germs	3	2
Sick child	ca 11	Germs make kids sick	3	3	haj 10	Sick child because of micro-organisms	3	3	hai 65	A sick child has a germ because it has a very red rash	4	4
Sick child	ca 9	Have germs and micro-organisms in them	2	3	haj 57	Causes illness	3	3	hai 75	Because germs are diseases and they float in the air	2	2
Sick child	ca 2	Makes child ill	3	3	haj 61	The baby is full of bad germs	2	2	hai 47	Because the baby has germs	2	2
Sick child	Ca 58	Germs make the child ill	3	3	haj 66	Germs made the child sick	3	3	hai 76	The baby has germs because he is sick	3	3
Bread	ca1 1	Germs breed on the bread	1	2	sm 34	This bread is on the table but the table has got germs on it so the bread gets the germs as well	1	1	tb 31	No comment	0	0
Bread	ca 4	Contains yeast which is a micro-organism	3	3	haj 10	Healthy (micro-organisms)	2	2	tb 28	Germs in the kitchen	1	1
Bread	ca 58	Micro-organisms got into it	2	2	haj 57	It is fresh and clean and not mouldy	1	1	hai 25	It might have been on the floor and on dirty things	1	1
Bread	ca 67	Contains yeast	3	3	haj 61	Bread is made with yeast which is full of micro-organisms	3	3	hai 30	Not germs	1	1
Bread	ca 51	Micro-organism to make bread	2	2	haj 66	Made with yeast	3	3	hai 72	No comment	0	0
Sour milk	ca 78	This has gone off, if somebody drinks this they can become very ill	2	2	haj 3	micro-orgs are in	2	2	hai 15	So if you drink it you will get germs	2	1
Sour milk	ca 11	Germs make the milk go sour	3	3	haj 10	Make you sick because of micro-organisms	2	2	hai 79	This is a germ because it has been left outside	1	1
Sour milk	ca 2	Causes milk to go sour	3	3	sm 5	Micro-organisms make things go mouldy or sour	3	3	hai 28	Sour because it has germs in it	3	3
Sour milk	ca 65	Gone off food	1	2	haj 79	Sour because of micro-orgs	3	3	si 45	You would be ill because it is off	2	2
Sour milk	ca 67	As it gets older it turns mouldy	1	1	sm 2	Has germs	2	2	hai 25	Its old and rotten	1	1

Compo st heap	ca 1	Bodily waste germs	1	2	haj 3	Germs are existing in	2	2	hai 31	You could catch germs if red ants were in it	1	1
Compo st heap	Ca 11	micro-organisms beak this down	3	3	haj 10	Gives of a bad smell	1	1	hai 72	Baby might eat the compost and get ill	1	1
Compo st heap	ca 4	Germs break down the compost	3	3	sm 5	Compost heap has lots of micro-organism init and around it	2	2	hai 73	Because animals have been in there and there are old things	1	1
Compo st heap	ca 64	Nasty smelly dirty place	1	1	haj 61	The grass in the heap may have been walked on by something dirty	1	1	hai 37	Has lots of germs because its dirty	1	2
Compo st heap	ca 27	Its full of micro-organisms	2	2	haj 66	Mud and dead plants are decayed by micro-organisms	3	3	hai 63	This is germs because it is all dirty	1	2

	Rater 1	0	1	2	3	4
Rater 2	0	2	0	0	0	0
	1	0	14	1	0	0
	2	0	5	14	1	0
	3	0	0	1	20	0
	4	0	0	0	0	2

Total horizontal	2	15	20	21	2
Total vertical	2	19	16	21	2

Total diagonal 51

Total agreement Σ a = 2+ 14+14+20+2 = 51 % Agreement = 51/60 = 85%

Expected frequency agreement by chance
ef = row x column ÷ overall

ef for 0/0 = 2 x 2 ÷ 60 = 0.06 ef for 1/1 = 15 x 19 ÷ 60 = 4.75 ef for 2/2 = 20 x 16 ÷ = 5.3 ef for 3/3 = 21 x 21 ÷ 60 =7.3

ef for 4/4 = 2 x 2 ÷ 60 = 0.06

Expected frequencies of agreement by chance
Σef = 0.06 + 4.75 + 5.3+ 7.3+ 0.06 = 17.47

K = ((Σa - Σef) ÷ (N - Σef)) = ((51 - 17.47) ÷ (60 - 17.47)) = (33.53 ÷ 42.53) = 0.78

Appendix 6

Interview with hai61

J	I was really interested in your picture, are these magnified? Can you tell me about it?
hai61	That was what they'd look like and if you looked closer, that was what they'd look like.
J	So can you tell me a little bit more about what you've drawn on there?
hai61	Um, once on this programme on TV, it was that programme where people um, get hurt and they said at the dentist that um, at the dentist place, that sometimes um, the germs that sometimes get in your teeth, they get scratched and sometimes um, that's how you sometimes get away because then they get weaker.
J	What sort of things do the germs do, do you think?
hai61	Um, they try and get inside our body to um, damage the important parts and um, we've got these sort of fighters in our body and they have to try and fight them away. To get them somewhere else, not on us.
J	Do you know what the fighters are in our body?
hai61	No.
J	What do you think a germ would look like on the inside?
hai61	Umm... It would um, have sort of um, it would have um, I think it would have cold blood and it would also umm, have um, sort of, little, tiny, not bones, but what our nose is made of. Just like a little tiny bit.
J	And, why do you think the blood would be cold in it?
hai61	Umm, because um, I think that um, the um, the um, if you felt it, it would feel cold, not hot.
J	Do you think all different, all germs look like this? Or do you think they look different?
hai61	Um, each one looks different.
J	Can you tell me any other ways, any types that you think there might be? What they might look like?
hai61	Um, I think there's these sort of spider type ones and.they sort of look like spiders, but not spiders.
J	Have you heard of different kinds of germs?
hai61	No.
J	have you ever heard of bacteria?
hai61	Yeah.
J	What about viruses?
hai61	A few.
J	What about fungus?
hai61	No.
J	Have you heard of micro-organisms?
hai61	No
J	Do you think they are the same or are they different?
hai61	Um, they're different, some of them do different damages to us.
J	Mhm. Do they cause different things?
hai61	Um, some cause different things and some cause the same things but they do it in, they do it in more harm. It's easier for them to kill.
J	You added some information on here, and um, and lots on the other side. Where, where did you find out all the information? How did you know it all?
hai61	Um, um, some I got um from overhearing my Mum and Dad,and some I um, hear on the TV and just bits and bobs from the radio.
J	Do you know anything else about germs that you haven't written down there?
hai61	Umm..
J	What sort of things they might do?
hai61	They jump from one place to another when, and we can't see it.
J	And what's the most important thing that you know about them?
hai61	Um, that you've got to try and make sure they don't get to your heart or your brain.
J	And why is that important?
hai61	Um, because if it gets to your heart, your heart might stop um, um, beeping and if it gets to your brain you um, you might stop thinking and, and you wouldn't probably wouldn't be able to see very well then because you wouldn't be able to think.
J	OK. What's not so important? What really doesn't matter?
hai61	Um, that um...I don't know.
J	Do you think they're mostly harmful or helpful?
hai61	Um, some are harmful, some are helpful.
J	So what sort of things do they do?
hai61	Umm, they can damage you and make um, you not um, walk and sometimes they can make your legs all puff up.

J	Mhm. And what about helpful things? Do you know what they do when they're helpful?
hai61	Um...um, the umm, the ones that are inside broccoli, my Mum says that they um, they make your eyes see.
J	Mhm. Have you ever seen any of them in real life?
hai61	No.
J	Do you know why you haven't seen them?
hai61	Um, because um, you um, you can't um, see them and you and you also you wouldn't like carrying a magnifying glass round looking at all people's hands and faces.
J	Why would you need that?
hai61	Um, because they're so tiny.
J	Do you know, have you any idea what kind of size they are?
hai61	Umm, um some of them are a size as when you sharpen a pencil, really is the size of the end.
J	Do you think they're all the same size? Or do you think they're different?
hai61	Some are bigger than others.
J	Would you like to have a guess at which ones are the biggest?
hai61	Mmm. Don't know any.
J	Do you think they're living things?
hai61	Yes.
J	And why do you think they're alive?
hai61	Um, because um, if they were not alive, they wouldn't really be able to get inside your body and they wouldn't be able to think of how you get inside your body.
J	So how do hey think?
hai61	Um, they haven't really got a brain but it um, it's something that, they've got sort of a rememberence and they get um, they originally get told of how you get um, the different kinds, they get told how you get from one place to the other. That you want, that that bug wants to destroy the place that it destroys.
J	So, how do they get told?
hai61	Um, I think um, that a Mummy sort of reduces it into them.
J	Do you think they're plants or animals or are they neither?
hai61	I think um, they're sort of both.
J	OK. Is there anything that makes you think that?
hai61	Because they're like an animal because they sort of can move and they've got a brain. And because I think they're plants is because um, they, I don't think they lay eggs, just like um, they don't lay their babies just like they're just popping out their tummy. I think they sort of lay these sort of seed things.
J	Where do you think you might find them? What places do you think you might find them?
hai61	Umm, in your, on your hands and um, if you've been walking on the grass they've eated, or somewhere that they've eated, you might find them on your feet.
J	Mhm Anywhere else?
hai61	Um, you can find them on animals as well.
J	And what sort of things do they do when they're on your hands and your feet or animals?
hai61	Um, they, um, they get inside your, try and wriggle inside your hands and then try and attack the bit that they want on you.
J	OK I've something to show you .....there's a peach. What do you think is happening to the peach?
hai61	Um, it's going off.
J	What's happened to it?
hai61	Um, because it's gone off because um, plants um, they, um they grow and, and they get to this stage when they get too old and all the sap that's in them, they, all the stuff that's in them can't, um, hasn't got enough, because if they were on the tree it wouldn't do this because um, the tree would, has fruits and then it, it can get the water and stuff that it needs to develop.
J	So, it's because it's been taken off the tree?
hai61	Yeah.
J	That that's happened. So there's nothing else made it happen? It's just, it just happens?
hai61	And um, if you peel some fruit, it makes them go brown.
J	Mhm. What will happen to the peach in the end?
hai61	Um, it will sort of crumble up.
J	Will you be able to see anything?
hai61	Um, you will just be able to see, sort of, the inside of the peach gone sort of browny.
J	And will there be any peach left?
hai61	Um, um there might be just the skin sort of gone all brown.
J	Do you think this is a good thing or a bad thing?

hai61 Bad.
J And why do you think it's bad?
hai61 Um, because if you sometimes eat one that's like a year old, it can sometimes give you some germs.
J And how would it give you germs?
hai61 Um, because the oldness, it wouldn't give you any goodness and, and because it's gone off, it might give you some badness.
J Is there any time when you think, when something goes off like that, that it's a good thing?
hai61 Um...
J It's OK. Do you know what a compost heap is? Do you know what happens inside a compost heap?
hai61 Um, lots of insects go in it.
J What do they do?
hai61 Um, they um, poo and wee in it and poo and wee um, gets um, is all germs because um, they, it's gone inside them and picked up the germs that were inside them and then gone out.
J Do you think that's a good thing or a bad thing?
hai61 Um, a bad thing.
J And why is it such a bad thing?
hai61 Um, because if you like, put you hand in it and then forgot to wash them when you were having your dinner um, the germs that were on there like, if there was just some bits of poo on you and you stuck your hand in your mouth, it might, you might accidentally swallow it, it with a bit of food and then you might get a bit ill, or something.
J There's a picture of some sewage works. Do you know if germs have got anything to do with sewage?
hai61 Um, they have got something to do with sewage.
J Do you know what they do?
hai61 Um... no.
J Can you think of any times when germs might be useful in nature? When they're used in nature?
hai61 Um, sometimes germs are used to put in medicines.
J How, what do they do , how do they help?
hai61 Um, the germs, some, the good germs make us good and then they put some bad germs into them, our own body fighters can help um, can just practice fighting for a real emergency in your body.
J OK. I've got some yoghurt, got some bread, got some cheese and some soy sauce. Do you think germs are used to make any of this food?
hai61 Um... I think there's some in cheese.
J Mhm. Do you know what they do, in the cheese? How do they make the cheese?
hai61 Um, they use it from milk and sometimes the milk hasn't been cleaned properly and it um, and it might get some of the cow's germs, or the goat's germs. Whatever cheese it is.
J Do you think there's any other kinds of foods that germs are used to make?
hai61 Umm...um, all sort of vegetables 'cause they all um, they've got like vitamin C and vitamins like, like good germs.
J So, do the germs make the vitamins?
hai61 Um, the vitamins, they put like um, they put like some um, good plant in there that had some good germs in it and then they sort of grind that up to make a vitamin.
J OK. This person's got a cold. How do you think she got her cold?
hai61 Um, sometimes it's been passed on from another person and sometimes it's because she's got too cold. And um, sometimes it's because um, another person who has got a cold has um, sort of gone up close to her and then she's got the cold.
J Do you think that's the way you get every kind of illness?
hai61 Um, no. Some get carried on animals 'cause like the um, the rat in the fire of London plague um, it carried it around, all the flies around.
J Have you ever had a cold?
hai61 Yes
J Do you remember how you got your cold?
hai61 It was because my Mummy got hers from work and then, um, I always stay in my Mummy's bed and then she passed in on to me and then I lost it over to my brother and then, and then my brother lost it over to my Daddy and then my Daddy lost it out of our family.
J So what do you think is happening inside your body when you're getting better?
hai61 I think the um, army man's they sort of fighted it away and then my body, and then they didn't have to do so much work so then they relax.

J	Mmm, have you ever had any other illnesses?
hai61	Once I've had chicken pox.
J	And do you remember how you got your chicken pox?
hai61	Um..
J	Do you remember, can you think how you got better from the chicken pox?
hai61	It was because my um, Mummy took me to the doctor and the doctor said take um, take this um, take some Calpol and then I took some Calpol and so in the morning it, um, I didn't have it.
J	So how, how do you think, how do you think your body was working with the Calpol?
hai61	Um, the Calpol was giving my army things more sort of strength.
J	Have you ever had any antibiotics?
hai61	No.
J	Do you know what they are?
hai61	No.
J	Do you know how they work?
hai61	No.
J	Have you ever had any injections or vaccinations?
hai61	I've had injections.
J	Do you know how they work?
hai61	Um, because um, they um, every so often you have to have them because they need to check your body to see if it's going well and again they put some good um, liquid that's got um, germs and some bad ones to, from make it practice, um, practice fighting them.
J	Mhm. OK. Do you think all, all illnesses come from germs?
hai61	No.
J	Do you know any that don't?
hai61	Um, some illnesses um, come from coldness because um, once I was, in Winter I think it was, and we went up to Scotland and I slipped in an iced pond and then my fingers started, bleeding because it was of the coldness.
J	Alright. OK. Is there anything you want to add to that?
hai61	No
J	That's excellent. Thanks ever so much!

Appendix 6

Interview with sj53

J	I was interested in the pictures and I just wanted you to tell me a little more about that, how and why you drew the things like that.
sj53	Well I just think, I know that you can get good microbes that like help you make different foods and bad ones that cause diseases and… things
J	So why did you draw them like that?
sj53	just because um, that one is sort of smiling 'cause it's good but they don't look like that
J	What do you think they do look like?
sj53	Um, well I think viruses are like, sort of… well they're all really small, and they're too small to see. You can only see them under a microscope. And um, you can see the effects of them, and I think viruses are sort of tiny balls with sort of spikes, well not spikes but, things coming out of them. I think they look all um, they look all different, well different types look different.
J	What different types of viruses, or…?
sj53	Um, different types of microbes, bacteria, fungi
J	OK. What about bacteria, what do you think they might look like?
sj53	Um, They'd be like um, sort of, a bit like a rectangle but with rounded off edges
J	What do you think the spikes on the virus might be?
sj53	Um, they might help stick to things or sort of um, inject the disease into your blood cells
J	OK, have you any idea what the things might look like on the inside?
sj53	I think they're, well they're not like humans 'cause they haven't got, um, maybe a sort of a gut, but um, not like a heart or anything.
J	So they're not like humans on the inside?
sj53	Um, maybe 'cause I think they breathe, but, I don't think they have lungs really…
J	How do they breathe?
sj53	Um, I think...because they're small I think they just, um, the oxygen, um, ah, comes into them and they, sort of, when it comes out its carbon dioxide.
J	OK, so they, they probably all look different, why, why do you think they are different?
sj53	Um, 'cause I think they give you, well they give you different diseases
J	And, and would you say they were all different from each other?
sj53	Yeah…yeah
J	How would you say they were the same, how do they relate to micro-organisms?
sj53	Well they're all microbes, and um, and I think, some of them, I think viruses are bad, bacteria can be good or bad…'cause I think they make food, foods, but, they can be dangerous um, fungi, fungi…I think it helps, well it, and it sort of grows on compost heaps, or on rotting wood… dampen, damp places. I think all of them grow in damp places.
J	What about germs?
sj53	Um, I think germs are sort of… is it sort of a word, just for all of them? Sort of slang..
J	Where did you find out all of this information?
sj53	Um, well, on the internet and in books just when you're sort of looking around for something else you find something on it, and you just start to read it,
J	Is this at home?
sj53	Yeah, and at school we did a big topic on micro-organisms.
J	Can you tell me anything else that you haven't written down about micro-organisms?
sj53	I can't remember what I wrote, um, um, they don't like too much sugar, because when people preserve stuff they um…that's why jam is called a preserved 'cause it's got lots of sugar in it, and they don't like salt… 'cause on like ships and in Tudor times, they used to have salted meat and it kept and they used to soak it and the salt would come out.
J	What's the most important thing you think you know about micro-organisms now?
sj53	Um, well, that they're good and bad I think… because they can make, can be really helpful with bread and um, yoghurt and things…but they also can be really bad and they can kill people, if you're not careful and they're easily spread and, so if in the kitchen you don't wash your hands, or you don't wear an apron, or you don't tie your hair up um, it can, all the, it, you could spread them or if you don't put your hand over your mouth when you sneeze all the bacteria you sneeze can go into the food and infect it.
J	OK. What's least important?
sj53	Um… I think maybe what they look like under a microscope, I think but… because um, it doesn't really make a difference to how, how you keep away from them, but scientists have got to recognise them if they're looking into a new

disease and they want to try and find what might, which microbe caused it, but I think a lot of things are quite important about it.

J — Are they more harmful than helpful?

sj53 — Um, yeah I think so, but bacteria help make food

J — What about viruses?

sj53 — I think they're all bad, 'cause when people have a cold or something they say 'oh I've got a virus'

J — What about fungus?

sj53 — I think they can be bad because they have spores that can be dangerous but um, they help rot, well, they grow in compost heaps which rot things away and if um, things didn't rot away then there would be so many things in the world that we couldn't get rid of... but they only rot away natural things.

J — OK. So, have you ever seen any of these in real life?

sj53 — No I don't think so..

J — And why is that?

sj53 — Um, because they're too small to see.

J — Do you have any idea of how big they might be?

sj53 — Um, very, very small.

J — Can you hazard a guess?

sj53 — Well, I think I saw something like you could fit about, um, about a million or something on a thumbnail.

J — Which ones are bigger and smaller?

sj53 — Um, I think viruses are bigger

J — Why?

sj53 — 'Cos they're bad.

J — Are they all alive?

sj53 — Yeah

J — How do you know?

sj53 — Because they um, because they perform the life processes

J — What sort of things do they do then ?

sj53 — Well um, for producing young, well, offspring, they multiply 'cause they can, a disease starts off not very, a cold, well, a disease can start off sort of very insignificant but then it gets worse and worse.

J — How come it get worse and worse, the virus?

sj53 — Because um they split in half and there is just more of them.

J — And is that true for all of them, bacteria, virus, and fungi?

sj53 — Um, yeah, I think so

J — So do you think they're plants or animals?

sj53 — Um, neither.

J — And where do you think might find them?

sj53 — I think you find them. I think they're everywhere, because in foods and um, infected foods, then, in your body 'cause there's um, that help you in your body.

J — Where about in your body?

sj53 — Um, in your gut, um...

J — What do they do there?

sj53 — I think they help digest your food, but I'm not sure.

J — Anything else?

sj53 — I think you find them where, most places where people have touched and if they don't wash their hands really, really, really well.

J — Here's a peach . What's happened to the peach?

sj53 — It's gone mouldy.

J — Do you know what it's caused from?

sj53 — Bacteria.

J — And what do the bacteria do?

sj53 — They eat it.

J — What will happen to the peach in the end?

sj53 — Um, I think it will go into gas.

J — So will you be able to see anything left?

sj53 — Um, I think if the bag's sealed, it might blow up. Well, not blow up as in explode, but inflate.

J — What's happened then, in that case? What would the bacteria have done to the peach?

sj53 — Well, they eat it, they eated it and then um, sort of excrete carbon dioxide.

J — OK. Do you think that's a good thing, or a bad thing?

sj53 — Um, I think, it, it could be good if, if um, yeah, it's good, because if you um, sort of had everything in the world um, and it wouldn't rot away, then it would be just a wasteland and everything would be piled up. And there would be not enough space to ah, bury all the bodies that died 'cause they rot away.

J — Do you know what happens inside a compost heap?

sj53 Um, well all the um, all the bacteria eat the, they're um, sort of bugs, but the dead things, the leaves. And they rot it down so it's, so it's not there and it turns into compost, or soil.
J Why is that a good thing?
sj53 Um, so there's um, well, like the rotting bodies. So there's sort of, not much stuff and you can use the um, compost or soil to um, on the garden.
J Why is it useful on the garden?
sj53 Because it's um, because it's rotted away sort of things in itself and it's quite dense, moist.
J Do micro-organisms have anything to do with a sewage works?
sj53 Yeah, because the water's dirty, and it helps things rot away. Rot away.
J How does it help the things to rot away?
sj53 Um, well it eats them. I think.
J What eats them?
sj53 Um, the bacteria.
J OK. Do you think micro-organisms have anything that helps in nature?
sj53 Um, well again, they rot away stuff and, so it isn't all piled up and um... like the compost, it helps things grow.
J OK here are some foods, do you think micro-organisms are used for any of these products?
sj53 Yeah, all of them.
J Do you know what's used in them?
sj53 Yeast.
J For all of them?
sj53 Yeah.
J How does the yeast work?
sj53 Well the, the um, bacteria... no, I think the yeast is bacteria, and it um, sort of, because bread is from dough and it, when the um, bacteria, the yeast excretes carbon dioxide um, it's, makes it, inflates it. So it's not so stodgy.
J Mhm. What about yoghurt?
sj53 Well it turns it from, it makes it thicker, from milk.
J How does it make it thicker?
sj53 Um, um, I think it sort of churns it up and adds carbon dioxide in to it.
J And cheese?
sj53 I think the same.
J And soy sauce?
sj53 Um, I think the same again.
J OK. Well, this person who is sneezing, what do you think they might be suffering from?
sj53 A cold.
J Mhm. And how did they get a cold?
sj53 Um, if someone who already had a cold sneezed on them.
J Any other ways?
sj53 Um, if they touched, or if had um, germs on their hands and touched another person.
J Is that how all diseases are caught, do you think?
sj53 Um, no.
J What other ways can you catch a disease?
sj53 I think you can get, get them if you touch um, infected food... or surfaces.
J Have you ever had a cold?
sj53 Yeah.
J How did you get it?
sj53 Um, I was sneezed on, I think.
J How did you get better?
sj53 Um, I think I just, you just get better.
J You just did?
sj53 Yeah
J What happens, do you think happened inside you when you got better from your cold?
sj53 Well, I think, in your blood, um, I think you have the bacteria and the blood cells and then you have antibodies in your blood which help um, fight the disease.
J Where do the antibodies come from?
sj53 Um, I think they're in your body already.
J Right. And what do they do to the disease?
sj53 I think they sort of um, have it in their body's so they're bigger than the bacteria.
J Right. So they um, what do they actually do?
sj53 I think they sort of eat it.
J Have you ever had any other illnesses?
sj53 Yeah, um, abscesses, chicken pox.
J How did you get that?

sj53 Um, by um, touch, for the chicken pox, um, and the abscess, I think the um, I'm not sure how I got them.
J OK,. Do you know how you got better from chicken pox?
sj53 Um, I think you get better.
J Just naturally?
sj53 Yeah.
J Have you ever had any antibiotics?
sj53 Yeah.
J Do you know why you had them?
sj53 Um, to help fight a different sort of disease.
J Do you know how they work?
sj53 I think they're extra antibodies. I think... but they're germs, bacteria.
J What do you mean, they're germs?
sj53 Um, I think they're good bacteria like the ones in your gut that helps fight the bad ones.
J What about vaccinations? Ever had any?
sj53 Yeah.
J Why did you have them?
sj53 To keep, to help stop, so I don't have any really dangerous diseases... like um, small pox or meningitis.
J Do you know how they work?
sj53 I think they give you um, some sort of the actual disease and then the antibodies help fight it, but it's not very much, so they um, they make a special type of antibody. A special one that will, I ever get the disease, then will fight it, it will fight it immediately.
J OK. Do you think all illnesses come from micro-organisms?
sj53 Yeah.
J We're finishes but is there anything else you want to say?
sj53 No.
J OK. Thanks a lot. I've really enjoyed talking to you.

Appendix 6

Interview with ca94

J Can you tell me a little bit more about your drawing?

ca94 Well, I have, I know sort of what a micro-organism is. I know it's like a living thing and like very small, but like, I just know that most cells have got things like that, so that's why I drew it

J What do these things do?

ca94 Yeah, I know ah, that one's like, the main like, it it's like a brain sort of thing. And the cell wall's like protection, but its like, can't really explain. It's like, just the cell wall but its smaller than that (pointing at the drawing)

J So can you imagine how small?

ca94 Small enough to see through one of them little micro-scoff things.

J And what do you think this would look like inside?

ca94 Just tiny little yellow, like a little colour, or red or something, maybe.

J And why would you think it would be those colours?

ca94 Don't know.

J OK. Do you think all micro-organisms look like that? Do you think they're all similar?

ca94 Most of them, but I doubt all of them.

J OK. Have you heard of different kinds of micro-organisms?

ca94 We've done it but, I can't really remember.

J Have you heard of bacteria?

ca94 Yeah.

J Fungus?

ca94 Yeah.

J Viruses?

ca94 Yeah.

J Germs?

ca94 Yeah.

J How are they related to one another?

ca94 I know that um, like micro-organisms... uh, you can get bad and then you can get good, can't ya? And like, I know that um, you get it in bacteria, and things like that, a lot. And then, that's it really.

J So are the bacteria the same things as micro-organisms, or are they different would you say?

ca94 Um, I thought that there, micro-organisms were in the bacteria. So like... It's like, you can get, oh, I don't know how to explain it now, I feel really silly! You can get like, good ones but you can get bad ones and the good, the bad ones are the kind that make germs like, make people ill and things like that.

J OK. And then you've added quite a lot of information there. Where did you find out all the information?

ca94 I just know it's in yeast and things like that, 'cause we learnt it once and like.

J Can you remember where you learnt it?

ca94 Yeah, I learnt it in like, class and things like that. I think. But I watched a programme once on tele.

J OK. And do you know anything else about micro-organisms that you didn't get a chance to write down?

ca94 No, not really.

J What do you think's the most important thing that you know, if you were to tell somebody an information fact about micro-organisms, what would be the thing that you tell them?

ca94 It lives in a lot of things, like, it's in yeast and yeast is in like, a lot of like, bread, cheese, beer and things like that.

J Mhm. And what's not so important?

ca94 That it's tiny.

J Do you think most micro-organisms are harmful or helpful?

ca94 What like, good ones? Or, some can like, 'cause germs can make you ill, so there's some like, that are bad. But then you've got like, the ones in the food, so you can eat some, so it must be good as well.

J Have you ever seen any of them?

ca94 Nuh, like viruses and things like that I've seen.

J Where have you seen those?

ca94 Like, people ill and like, you see them in like, the videos that teachers show you at school and things like that. And, I've seen, oh there's a couple but you just can't remember!

J OK. Have you ever actually seen one, or any of them in real life?

ca94 Not like, actually just on tele and things like that.

J So why would you think you haven't been able to see them?

ca94 'Cause like, it's where there're germs and like, illness, someone could easily catch illness. So if it was in school, you wouldn't want anybody being ill, would ya?
J Mhm. No. And how big do you think they are?
ca94 Very, very, very, very small.
J Any idea on size?
ca94 No. I'd say smaller than that in millimetres.
J And do you think they're all about the same size, or do you think they vary in size?
ca94 I think they're like, not all the same size 'cause like, you can get different types. It depends how they build together, and things like that.
J Have you any idea which ones might be bigger and which ones might be smallest?
ca94 I'd say um, virus would be quite big, if you can get ill over it.
J Do you think they're alive?
ca94 Yeah.
J What do they do to, you know, how do you know that? What sorts of things do they do to tell you that they're alive?
ca94 I just know it! It's all the things that we learn.
J Yeah, do you know what they might do that tells you they are living?
ca94 I'm not very good at things like this...
J OK. Do you think they're like plants, or are they like animals, or neither?
ca94 Um, the fungi is like a plant sort of thing.
J And why is that?
ca94 'Cause I've heard about it, well no, I haven't heard about it, but it sounded like um. Is it that there's like, I know this sounds stupid but I've got this like this questionnaire science book and it says like, um, like about fungi's and things like that. And like, it's um, like a plant. It's not a plant, but it sort of looks like a plant.
J What about the others? Do you think they're more like animals or more like plants or you don't know, or neither?
ca94 No, I don't know, I don't think so just 'cause, I'd say they're like animals 'cause they're like living things and they move like, different places. But that's all I'd really say, if, like anything.
J How do they move?
ca94 I aint got a clue!
J And where do you think you can find them?
ca94 Bread, well pretty much yeast. Um, you can find them in like, um, bins and things like that, where loads of germs are. You can find them on people as well. 'Cause like, where there're germs a lot of people have got those, like colds and things like that.
J So, in particular, where on people would you find them?
ca94 Around people. Oh God. Maybe like, hands, it depends what sort of relationship you have with that other person because you could be like kissing, things like that.
J And why are the micro-organisms in those particular places? Why do you think you would find them in those places?
ca94 Don't know.
J OK. What sort of things are they doing there? Why are they there?
ca94 Because that's like, you find them there because that's where the germs are because like, where they're bad you find loads of germs, because like and bins and things like that. And that's all I really know.
J OK. I have peach to show you
ca94 Eugh, that's sick!
J Do you know what's happened to it?
ca94 It's like, gone all mouldy. Rotted. Sort of thing. It's not all the way, yet. But like, the um, like the bad like, when I was saying earlier, you get good germs and bad germs, the bad germs have got like, all bad. Like um, overtook sort of thing. They've like made it all go minging and mouldy.
J And what'll happen to it, if it just gets left and left?
ca94 It will, mould!
J What will it look like?
ca94 That, but all over. And then they eventually do get smaller.
J The peach will get smaller?
ca94 Yeah. But not smaller, smaller. Where it will rot, it'll start, will be going into a different shape and things like that.
J So what will happen to the bits of the peach in the end?
ca94 Put it in the bin like a normal person!
J Yeah, but what would happen to it if we didn't? If we just left it and left it and left it?

ca94 It'd just keep on rotting until like, horrible smell, things like that, and like um, it, some of it would like, just rot away I suppose.
J So would you be able to see any of it, or not? Would there be anything left?
ca94 I'd say there'd be little bits left, but not much.
J And where's the rest of the peach gone?
ca94 Don't know.
J And is that a good thing or a bad thing?
ca94 Bad.
J Mhm. And why is it bad?
ca94 Because like, you wont be able to eat it, because it's all mouldy and horrible.
J And can you think of any times when it might, when rotting or decaying might be a good thing?
ca94 No.
J OK. Do you know what a compost heap is?
ca94 Yeah.
J Do you know what happens inside a compost heap?
ca94 Oh, yeah, it um, that's all like, it's good then, like it's um, that's all the like, germs and things like that, but it's good sort of germs. It's like all the, 'cause my Grandpa's a bit of a gardener. And um, it's got like, loads of good micro-organisms.
J Mhm. OK.
ca94 I'm not sure what happens in it.
J And is it a good thing?
ca94 Oh, 'cause I think, don't it, if it's in like um, near plants. It's sort of like a, not a nutrient, but it's like, it helps it a little bit.
J Here's a picture of some sewage works, do you think micro-organisms have anything to do with sewage works?
ca94 Well, they're in germs, so like, it's in, other like, germs... like, can't explain it, it's hard to explain. It's like, it's sort of like... It's all the sewage which contains like, loads of dirty bacteria, things like that, waste.
J Can you think of any time, um, when micro-organisms might be useful in nature or the environment?
ca94 They're like, useful in composting, like we were saying earlier, and um, I'd, it's good because like, you, sometimes it's all like, you've got it in beer and things like that but there's nothing really else I know.
J OK. We've got some food here, some brown bread and yoghurt, some cheese and some soy sauce.
ca94 Is it in soy sauce? I never knew that.
J Which ones are micro-organisms used to make?
ca94 Yeah. And um, what, like, helps it cook and things like that? I don't, I know bread's one and I think cheese might be one.
J OK. Do you know what kind of micro-organisms are used in the bread?
J OK. Do what they do in the bread, or the cheese, to make it?
ca94 I know, sometimes they make the bread go like more, it makes it um. 'Cause it's in the yeast and it, so it makes the bread um, like I can't, oh, what's that word?
J Makes it rise?
ca94 Yeah, that's it!
J OK. Do you know any other foods that are made wit the help of micro-organisms?
ca94 I know it's in beer. It's in, got cheese, oh God. Trying to think!
J It's OK, here's somebody with a cold. How do you think she got her cold?
ca94 By germs being passed on to her, or, bad germs in her, things like that.
J So how do they get passed on?
ca94 What, like, on to her or? Like earlier, I was talking about people and things like that? I don't know how it started.
J OK, And do you think all diseases are caught, from one person to another?
ca94 Not all, but I'd say some. 'Cause some diseases like, when you get things like athlete's foot and things like that, that's like, not your own fault, but it's all down to you. I think.
J Do you mean that you're responsible?
ca94 Yeah.
J Mhm. OK. Have you ever had a cold?
ca94 Yeah, I've got one at the moment!
J How did you get it?
ca94 I think it's 'cause like, I go out with wet hair sometimes . I always get colds.
J Do you know how you get better from your colds?
ca94 Sometimes I like, take like, not um Paracetamol. I take like Beechams and things like that, 'cause they're good for colds.
J Do you know how they work?
ca94 No!

J	Can you imagine what's happening inside your body when you're getting better from a cold?
ca94	No .
J	Do you know what's happening with say, the Beechams and your body?
ca94	I'd say they're killing all the bad germs, sort of thing.
J	OK. And have you had any other sort of illnesses?
ca94	Not bad ones. I've had tonnes of like colds and like, yeah just things like that, and I get tonsillitis a lot.
J	Do you remember how you got your tonsillitis?
ca94	No, it just comes to me.
J	And what do you do to get better from your tonsillitis?
ca94	Go to the doctors, and they give me some medicine. Not special. It's just got one of them big names that you can't really say!
J	So, have you ever had any antibiotics?
ca94	Yeah.
J	Do you know why you had them?
ca94	Yeah, I had 'em 'cause I had conjunctivitis in my eye one time.
J	How do they work?
ca94	Same as the Beechams, I think.
J	Mhm. And have you had any vaccinations?
ca94	No. But I've gotta have one of them, I've got to have one of them tomorrow.
J	Have you?
ca94	Tonight. And then I think they've just got to check my blood and things like that. 'Cause up, I'm going to Turkey. So I've got to have one of them.
J	Do you know why you've got to have one when you go to Turkey?
ca94	Yeah, because they have um, like, really bad illnesses over there. Oh, what's the name of it? I forgot what it's called. I know, like, I've got to have a tetanus jab. I think that's what it's called.
J	And do you know how that works?
ca94	No.
J	Ok, we're finished now, is there anything else you want to add?
ca94	No, not really.
J	Well, that's really great. Thanks.

Appendix 7

Amalgamated data for the development of typologies

MODEL: Classification -Grouping			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	19.1%	52.4%	70.9%
Transitional	54.7%	31.3%	19.1%
Emergent	30.2%	21.7%	15.7%
Interviews			
Extended	0/10	7/11	5/9
Transitional	6/10	2/11	4/9
Emergent	4/10	2/11	0/9
Typology			
Strongly held	Transitional	Extended	Extended
Moderately held	Emergent	Transitional	Transitional
Weakly held	Extended	Emergent	Emergent

MODEL: Classification -Terminology			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	0%	27.8%	55.6%
Transitional	0%	72.2%	44.4%
Emergent	31.4%	0%	0%
Brainstorms			
Extended	0%	69.6%	97.6%
Transitional	0%	30.4%	2.4%
Emergent	83.5%	0%	0%
Interviews			
Extended	0/10	4/11	5/9
Transitional	0/10	7/11	4/9
Emergent	10/10	0/11	0/9
Typology			
Strongly held	Emergent	Transitional	Extended
Moderately held	-	Extended	Transitional
Weakly held	-	Emergent	Emergent

MODEL: Morphology - External appearance			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	6.3%	24.7%	16.9%
Transitional	12.8%	27.7%	54.0%
Emergent	84.9%	53%	34.8%
Interviews			
Extended	0/10	2/11	1/9
Transitional	1/10	4/11	7/9
Emergent	9/10	5/11	1/9
Typology			
Strongly held	Emergent	Emergent	Transitional
Moderately held	Transitional	Transitional	Emergent
Weakly held	Extended	Extended	Extended

MODEL: Morphology - Internal structure			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	0%	2.4%	29.2%
Transitional	20.8%	36.3%	46.1%
Emergent	77.4%	56.0%	37.1%
Interviews			
Extended	0/10	2/11	5/9
Transitional	3/10	4/11	2/9
Emergent	7/10	5/11	2/9
Typology			
Strongly held	Emergent	Emergent	Transitional
Moderately held	Transitional	Transitional	Emergent
Weakly held	-	Extended	Extended

MODEL: Size and Scale			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings	26.4% small drawings	39.2% small drawings	39.3% small drawings
Extended	8.8% (comments)	13.3%(comments)	5.6% (comments)
Transitional	5.0% (comments)	9.6% (comments)	9.0% (comments)
Emergent	0% (comments)	0% (comments)	0% (comments)
Brainstorms			
Extended	7.9%	23.8%	44.9%
Transitional	3.6%	20.1%	21.8%
Emergent	0%	0%	0%
Interviews			
Extended	10/10	11/11	9/9
Transitional	0/10	0/11	0/9
Emergent	+ 2/10 (related to virulence)	+ 3/11(related to virulence)	3/9 (related to virulence)
Typology			
Strongly held	Extended	Extended	Extended
Moderately held	Transitional	Transitional	Transitional
Weakly held	Emergent	Emergent	Emergent

MODEL: Living and non-living			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	20.8%	38.7%	75.3%
Transitional	135.2%	100.6%	52.7%
Emergent	30.2%	21.7%	15.7%
Brainstorms			
Extended	0%	0.6%	23.1%
Transitional	18.65	56.2%	44.9%
Emergent	0.7%	1.8%	2.6%
Interviews			
Extended	0/10	0/11	5/9
Transitional	9/10	11/11	4/9
Emergent	1/10	0/11	0/9
Typology			
Strongly held	Transitional	Transitional	Extended
Moderately held	Emergent	Extended	Transitional
Weakly held	Extended	Emergent	Emergent

MODEL: Disease, health and hygiene - Disease and infection			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings			
Extended	0%	0%	0%
Transitional	0%	1.8%	2.2%
Emergent	5.7%	3.0%	2.2%
Brainstorms			
Extended	4 comments	0 comments	0 comments
Transitional	21 comments	75 comments	14 comments
Emergent	50 comments	20 comments	14 comments
Concept maps			
Extended	2.3%	2.4%	0.9%
Transitional	12.7%	35.5%	21.4%
Emergent	59.5%	31.4%	35%
Interviews			
Extended	0/10	1/11	1/9
Transitional	3/10	6/11	7/9
Emergent	7/10	4/11	1/9
Typology			
Strongly held	Emergent	Transitional	Transitional
Moderately held	Transitional	Emergent	Emergent
Weakly held	Extended	Extended	Extended

MODEL: Disease, health and hygiene -immunity, recovery and infection control												
Data source	**Year 2**				**Year 6**				**Year 9**			
Brainstorms Extended Transitional Emergent	 0% 3 comments 0%											
Concept maps Extended Transitional Emergent	SC 2.3% - -	VAC 0% 9.3% 13.3%	ANB 0% 10.4% 8.1%	BL 0% 3.5% 8.1%	SC 2.4% - -	VAC 1.2% 53.5% 7.1%	ANB 0% 58% 5.9%	BL 0.6% 21.3% 23.7%	SC 0.9% - -	VAC 4.9% 58.3% 4.9%	ANB 0% 57.3% 2.6%	BL 0% 47.6% 10.7%
Interviews Extended Transitional Emergent	 0/10 4/10 6/10				 1/11 6/11 4/11				 1/9 6/9 2/9			
Typology Strongly held Moderately held Weakly held	 Emergent Transitional Extended				 Transitional Emergent Extended				 Transitional Emergent Extended			

MODEL: Ecology - Location			
Data source	**Year 2**	**Year 6**	**Year 9**
Drawings Extended Transitional Emergent	 0% 5.7% 8.2%	 1.8% 10.8% 4.2%	 0% 0% 1.1%
Brainstorms Extended Transitional Emergent	 0.6% 18% 18.1%	 14.6% 30.5% 4.9%	 1.3% 17.9% 2.6%
Interviews Extended Transitional Emergent	 1/10 2/10 7/10	 2/11 4/11 5/11	 0/9 7/9 3/9
Typology Strongly held Moderately held Weakly held	 Emergent Transitional Extended	 Transitional Extended Emergent	 Transitional Emergent Extended

MODEL: Ecology - Decay and cycling of matter									
Data source	**Year 2**			**Year 6**			**Year 9**		
Drawings Extended Transitional Emergent	 0 0 0			 0 3 drawings 0			 0 0 0		
Brainstorms Extended Transitional Emergent	 0 0 0			 I comment 6 comments 0			 0 3comments 0		
Concept maps Extended Transitional Emergent	CH 0% 6.9% 27.2%	MB 0% 48.9% 20.2%	SM 0% 18.6% 15.6%	CH 1.2% 20.7% 15.4%	MB 4.1% 56.8% 13.0%	SM 1.2% 42.6% 18.3%	CH 1.9% 27.2% 18.3%	MB 0% 38.8% 21.4%	SM 0% 25.2% 24.3%
Interviews Extended Transitional Emergent	Peach 0/10 3/10 7/10	C. Heap 0'10 0/0 4/10		Peach 0/11 11/11 0/11	C. Heap 0/11 3/11 2/11		Peach 0/9 8/9 1/9	C. Heap 2/9 7/9 0/9	
Typology Strongly held Moderately held Weakly held	 Emergent Transitional -			 Transitional Emergent Extended			 Transitional Emergent Extended		

MODEL: Technological applications - food									
Data source	**Year 2**			**Year 6**			**Year 9**		
Drawings									
Extended	0			0			0		
Transitional	0			5 drawings			0		
Emergent	0			0			0		
Brainstorms									
Extended	0			0			0		
Transitional	0			33comments			13 comments		
Emergent	0			0			0		
Concept maps	Bread	Beer	Yogurt	Bread	Beer	Yogurt	Bread	Beer	Yogurt
Extended	0%	0%	0%	1.2%	1.2%	0%	2.9%	0.9%	0.9%
Transitional	0%	0%	0%	19.0%	4.3%	26.1%	34.0%	36.9%	20.4%
Emergent	1.7%	16.2%	4%	14.2%	19.5%	20.7%	10.7%	10.7%	26.2%
Interviews									
Extended	0			1/11			0/9		
Transitional	1/10			7/11			9/9		
Emergent	9/10			4/11			0/9		
Typology									
Strongly held	Emergent			Transitional			Transitional		
Moderately held	Transitional			Emergent			Emergent		
Weakly held	-			Extended			Extended		

MODEL: Technological applications - medical						
Data source	**Year 2**		**Year 6**		**Year 9**	
Drawings						
Extended	0		0			
Transitional	0		0			
Emergent	0		0			
Brainstorms						
Extended	2 comments		1 comment		0	
Transitional	0		19 comments		6 comments	
Emergent	0		0		0	
Concept maps	Vaccination	Antibiotics	Vaccination	Antibiotics	Vaccination	Antibiotics
Extended	0%	0%	1.2%	0%	4.9%	0%
Transitional	1.2%	0.6%	15.4%	18.9%	14.6%	7.8%
Emergent	21.4%	17.9%	45.0%	45.0%	48.6%	62.1%
Interviews	Vaccination	Antibiotics	Vaccination	Antibiotics	Vaccination	Antibiotics
Extended	0/10	0/10	1/11	0/11	3/9	1/9
Transitional	1/10	0/10	5/11	0/11	4/9	0/9
Emergent	2/10	2/10	5/11	6/11	2/9	8/9
Typology						
Strongly held	Emergent		Emergent		Emergent	
Moderately held	Transitional		Transitional		Transitional	
Weakly held	Extended		Extended		Extended	

MODEL: Technological applications - environmental			
Data source	**Year 2**	**Year 6**	**Year 9**
Concept maps			
Extended	0%	1.8%	0.9%
Transitional	0.6%	3.0%	8.7%
Emergent	27.7%	42.6%	37.9%
Interviews			
Extended	0/10	0/11	0/9
Transitional	0/10	0/11	0/9
Emergent	10/10	11/11	9/9
Typology			
Strongly held	Emergent	Emergent	Emergent
Moderately held	Transitional	Transitional	Transitional
Weakly held	-	Extended	Extended

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