

Using a concept mapping tool with a photograph association technique (CoMPAT) to elicit children's ideas about microbial activity

Abstract

Concept mapping is a technique used to provide a visual representation of an individual's ideas about a concept or set of related concepts. This paper describes a concept mapping tool using a photograph association technique (CoMPAT) that is considered to be a novel way of eliciting children's ideas. What children at 11 years of age know about particular concepts related to microbial activity is presented and discussed in relation to the effectiveness of CoMPAT as a tool to draw out their ideas. It is proposed that this tool could be used to explore ideas about this and other science concepts from children in other age groups, and where language may be a barrier to participation.

Introduction

Since their inception in the early 1970s, concept mapping techniques and their uses has continued to evolve (Novak & Cañas, 2007). This paper presents a new concept mapping technique that is part of that tradition and demonstrates the adaptability that makes concept mapping a useful way of collecting information about individuals' ideas. Because concept mapping is a flexible tool it can be tailored for use by almost any group of learners (Kinchin, 2000a). The challenge within the context of this research was to design a tool that would be accessible to, and manageable by all the children in the age group. Conventional concept maps require reading skills likely to be beyond some of the children in this study, including those for whom English is not their first language. A new technique, concept mapping using a photograph association technique (CoMPAT) was developed to accommodate these issues in order to be able to work productively with

a large number of children within a broad spectrum of reading ages. Photographs providing visual stimuli that were representative of specific concepts associated with microbial activity were employed. Using photographs rather than relying on words alone enabled all of the children in the sample to participate and produce their own concept map. Microbial activity encompasses some complex and abstract concepts. The difficulty of understanding abstract biological concepts has been recognised, for example, photosynthesis (Barker, 1995) or cycling of matter (Hellden, 1996) and conventional methods have been used to discover students' ideas. More recently Chang (2007) used an interview combined with a concept mapping approach to discover children's mental models of homeostasis. The purpose of this research was to discover if using photographs as visual stimuli would enable children to create concept maps that could provide an insight about their ideas of microbial activity.

Micro-organisms have an essential role in life on Earth and their metabolic activities have been exploited by humans since Babylonian times (Black, 2005). The manipulation of their genomes in ever more developing biotechnologies and their use in fields as diverse as medicine, mining and environmental remediation makes microbiology an increasingly important area of science that impacts on everyday life. However, there are few opportunities within the primary curriculum, in England, for learning about micro-organisms. This state of affairs provided the impetus for the research, as it seems essential to find out what children know and understand about microbial activities and related biotechnologies prior to further teaching (Dawson, 2003; Lock and Miles, 1993) if

they are to engage in meaningful debate about scientific issues (Millar and Osborne, 1998; Reiss, 2002).

The focus of the study was concerned with the effectiveness of CoMPAT as a tool to elicit children's ideas about microbial activity; as a result the following research questions were posed:

- Does the concept mapping technique (CoMPAT) enable children's ideas about microbial activity to be elicited?
- What do 11-year-olds know and understand about microbial activity?

Background and theoretical perspective

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). This research is framed within a constructivist view of learning science, which acknowledges that children construct their own knowledge in an active and dynamic manner and the ideas that children hold may not equate to scientifically accepted warrants and claims (Driver, 1989; Osborne, Wadsworth, & Black, 1992). It holds that children acquire ideas, in trying to make sense of scientific phenomena, from a variety of sources, including everyday events and situations (Driver, Squires, Rushworth & Wood-Robinson, 1994; Newton, Driver, & Osborne, J., 1999; Shepardson, 2002; Tobin, 1998). It is, therefore, not surprising to find that children's ideas about many scientific phenomena differ from the accepted view, and that these ideas may influence

further learning (Ausubel, 1968). Discovering the ideas that children hold about particular scientific concepts is now considered to be an important aspect of a constructivist approach to learning (Driver, Guesne, E. & Tiberghien, 1985; Osborne & Freyberg, 1985; Scott, 1987).

Concept mapping as a technique to discover the ideas an individual holds about particular concepts is underpinned by a constructivist epistemology (Novak & Gowin, 1984; Novak & Cañas, 2007). Concept maps have been used widely as pedagogical tools for planning, instruction, assessment or evaluation of learning (e.g. Barenholz & Tamir, 1992; Chang, 2007; Kinchin, 2000a, 2000b ; Mintzes, Wandersee & Novak, 2000; van Zele, Lenaerts, & Wieme, 2004; Yin, Vanides, Ruiz-Primo). Concept maps are a visual representation of the relationship between different concepts and allow individuals to indicate their understanding of the relationships between ideas, things or people (van Zele *et al.*, 2004; White & Gunstone, 1992). 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. Concept maps therefore provide an efficient mechanism for eliciting the relationships children may hold about concepts, in this instance, the concepts about microbial activity.

Participants

The 169 participants in this study were children aged 11 years. The research set out to find out what this age group knew about microbial activity after they had just completed a short learning sequence about micro-organisms based on the relevant National

Curriculum science programme of study for England (DfES, 1999) and . The children were drawn from three separate state schools in and near Southampton and provided a sample which was broadly representative of the age group in terms of academic ability, socio economic factors, gender and ethnicity.

The research tool - CoMPAT

Photographs provide visual, rather than verbal, prompts that may help to promote the elicitation of children's ideas by stimulating different intelligences (Gardner, 1999), and are thought to play a crucial role in the learning process (Alesandrini, 1984). The photographs were selected to be direct representations or analogies of the key areas of microbial activity that this age group is likely to have had some experience of, and they are all related to statutory teaching requirements in the English curriculum. Furthermore, they were images that had been most frequently selected by children during a previous smaller study (Byrne & Sharp, 2006). The photographs provided more examples of beneficial than non-beneficial microbial activity, which is more representative of reality, and tried to avoid well known brands that may have elicited a skewed response. An expert map, in which the most important links are presented, was not created to judge the maps produced by the children, as this was deemed unnecessary for the purposes of the study.

The photographs (Figure 1) are representative of the particular concepts associated with the key areas of microbial activity being investigated, for example, the sick child represents disease, the bread represents application of micro-organisms in traditional food

technology, and the mouldy bread represents decay. For this study, the key areas of microbial activity and the photographs that represent the concepts are:

- disease, infection control and health (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 were labelled to provide additional information to clarify what the photograph represented, in order to avoid misinterpretation, and to assist those children who prefer the written word rather than a picture. Children were allowed to ask what the label said, although they were given no further information. Two terms ‘micro-organism’ and ‘germ’ were also provided because some children in the earlier study by Byrne and Sharp were unfamiliar with the term micro-organism whilst others used both terms, often interchangeably.

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 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

encouraged to think of all the connections they could as some photographs have a number of inherent sub-concepts. The children were also asked to make connections between the different photographs and to add any additional ideas if they could. These instructions were given so that the completed maps would represent the level of complexity of the children's conceptual frameworks regarding microbial activity. The children were told that this was not a test and that they should state everything they could whilst it was expected that they would work alone and not share their ideas with anyone else. The research was conducted in the children's normal classroom environment and they were given as much time as they needed to complete their maps.

INSERT FIGURE 1 ABOUT HERE

Assessing the concept maps

The photograph concept maps produced by the children were analysed qualitatively and quantitatively. 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. The maps were categorised according to the concept map structures, identified by Kinchin, Hay & Adams (2000) that indicate the level of complexity of the mental model held by an individual. These are, 'Spoke' in which all aspects of the topic are related directly to the key concept only, 'Chain' in which each concept is linked to another in a linear fashion, and 'Net' in which concepts are linked in an integrated network.

The linking statements, known as propositions, (Novak & Gowin, 1984) between concepts also indicate the level and complexity of understanding and this was also employed in the analysis of the data. The propositions that children used with each

photograph were therefore 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, rather than provide an assessment score for each individual. White and Gunstone (1992) offer a scoring system based on Novak and Gowin's (1984) system that has been adapted for use here and includes both qualitative and quantitative approaches, these include:

- Recording which photographs were chosen;
- Recording all the propositions;
- Categorising the propositions;
- Recording absence of propositions or photograph;

In addition to scoring the number of propositions, their quality and accuracy were also analysed in order provide an insight into the depth of knowledge and understanding children have about microbial activity. A scoring system employing a five point scale (Table 1) similar to that used by Yin *et al.* (2005), was developed to provide an accuracy score for each photograph to determine the level of knowledge and understanding held by the 11-year-olds in this study.

INSERT TABLE 1 ABOUT HERE

Recent research has explored the reliability and validity of scoring systems (Kinchin 2000 b; Klein, Chung, Osmundson, Herl, & O'Neil, 2001; McClure, Sonak, & Suen, 1999), 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

using undertaken on a 15% sample of all the maps and using Cohen's Kappa (Cohen, 1960) was found to be 0.78, indicating a satisfactory level of reliability. Details of the criteria used to score each photograph are presented in Table 2. The scoring system specifically included alternative or non-scientific statements as valid contributions because they are frequently part of children's ideas and should be considered when developing learning sequences about a topic. In addition, the accuracy of the statements was not judged in terms of semantics or 'correct' usage of specific terms; instead the meaning of each statement was interpreted against the criteria. Frequency and percentage data were calculated for each photograph on every map. Table 3 provides a summary of the scores obtained.

INSERT TABLE 2 ABOUT HERE

Results and discussion

Eliciting children's ideas: use of photographs

Some children selected each photograph to produce their concept maps (Table 3). This indicates that, for them, the photographs were appropriate representations of the microbial activities that they were meant to depict. However it is noticeable that certain photographs were not included in the maps by over 50 % of the cohort. This rejection may be for two interrelated reasons. Firstly that the children did not know about the microbial activity represented in the photograph, secondly that the photograph had no meaning for them with respect to microbial activity, i.e. the photograph was not a clear enough illustration of the microbial activity it was meant to represent. The latter of these explanations would indicate that the microbial activity was less explicit within some photographs than others. However the research instructions asked the children to choose

the photographs that they thought had anything to do with micro- organisms, and a clear rejection based upon lack of knowledge seems to be a likely explanation. This is also supported by the relatively higher proportion of alternative statements (score1) elicited by these photographs compared to the photographs that were chosen more frequently. These alternative ideas provide a valuable source of information for teachers; by acknowledging them and planning lessons taking them into account they can help to develop children's ideas that are more congruent with a scientifically accepted view of microbial activity.

It is also noticeable that very few children offered a more advanced idea (score 4) about the microbial activity depicted in the photographs. This is not unexpected since the ideas anticipated at this level are more sophisticated than the taught curriculum requires for this age group. It is therefore interesting that at least some children provided advanced ideas indicating that they had acquired these ideas from somewhere other than school. This everyday knowledge could be exploited by teachers to provide more personalised learning and therefore more meaningful and richer experiences for these children.

INSERT TABLE 3 ABOUT HERE

Eliciting children's ideas: map structure

The majority of children (78 %) produced a 'Spoke' structure in which the photographs were linked to the main concept but not to each other. Figure 2 shows a typical example of such a map. Tom's map shows that he has a basic understanding of microbial activity in relation to some aspects of the three key areas explored. He knows that micro-organisms cause disease '*because micro-organisms cause diseases*', that they can be used to produce food and medicines '*because they use micro-organism in medicines*' and that

they cause decay *'it's been made mouldy by them'*. He has an appreciation of both some of the positive and negative aspects of microbial activity but the information he provides about each photograph is fairly basic, and there are no connections made between the photographs. Tom appears to know specific discrete facts about microbial activity but he has not related any of these to each other. Tom's map also illustrates some non-scientific ideas that were commonly held, about bleach *'it uses microbes for cleaning'*, and about milk *'it is made with and contains microbes'*.

INSERT FIGURE 2 ABOUT HERE

Concept maps showing a 'Net' structure were presented by 22% of the children. Most of the maps were not very complex and had only one or two connections linking photographs of closely related concepts. Table 4 shows the type and number of the linking propositions made. The commonest connection was between the photographs of antibiotics and/ or vaccination with the sick child. *'Antibiotics and vaccinations help stop sickness'* is a typical statement; this is not surprising as children of this age will probably have experienced both antibiotics and vaccinations.

INSERT TABLE 4 ABOUT HERE

Jane's map (Figure 3) shows three linking statements that are amongst the commonest elicited by the whole cohort; vaccination and antibiotics as medicines *'some microbes help you get better, these make you better so they are connected'*, food production *'micro-organisms help make yogurt, beer and yeast which is in bread'*, and the mouldy and fresh bread *'microbes need the right temperature so here they have put mould on the bread'*. Jane's linking propositions indicate that she is able to categorise particular photographs as representing the same concept. The difference in the complexity of the

two maps indicates Jane's understanding of some aspects of microbial activity is more developed than Tom's. Tom seems to have acquired separate facts whilst Jane has begun to collate those facts to form hubs of ideas around closely related concepts. It may be useful to have children produce maps together as a group, rather than as an individual exercise, so that they help each other construct and develop their ideas. Additionally, teachers could scaffold children's ideas by helping them explore connections beyond those expressed by the children here.

INSERT FIGURE 3 ABOUT HERE

However, Jane's other propositions do not illustrate any greater depth of understanding when compared to Tom's isolated statements, and the rest of the map is more like a 'Spoke' structure. Jane also cites the commonly held alternative idea that milk is made using micro-organisms. The understanding illustrated by the propositions is discussed below; this will provide insights into the depth of understanding about microbial activity of the whole cohort.

Eliciting children's ideas: Disease, infection control and health

Children's responses indicate that they have more ideas about this aspect of microbial activity, and that they have fewer non-scientific ideas in comparison to the other microbial activities - with the exception of ideas related to the photograph of bleach. The ideas that children hold are also interconnected, for example, the medical application of vaccines and antibiotics.

INSERT FIGURE 4 ABOUT HERE

- **Sick child**

The overall pattern of responses can be seen in Figure 4 and indicates that the majority of children at this age have some notion of the connection between disease and micro-organisms. Although a small number (7.1%) provided alternative (score 1) statements, for example, this ambiguous statement *'the illness the baby has is germs'*. The most common response indicates that this group of children consider micro-organisms to be the causal agent of disease and 26.0% of the children connect the photographs of antibiotics and/ or the vaccination to the sick child as a means to eliminate the micro-organisms *'antibiotics help to kill bad micro-organisms'*; *'gets rid of or prevents otherwise you might end up as a sick child'*. Only four children (2.4%) provided more sophisticated ideas, suggesting that the child was ill because of the effect of microbial activity *'the outcome of germs'*; *'micro-organisms have done something to make the child ill'*, although their ideas are relatively simple and imprecise and do not express any ideas about immune response. 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. Direct teaching or everyday experiences is evident in some responses where micro-organisms are referred to as 'bad' because they cause disease.

- **Vaccination**

A total of 54.5% of children (scores 2, 3 and 4) used the picture of the vaccination and responses indicate that vaccinations are understood to be related to micro-organisms as a means of eliminating them or the disease that they cause. The most common response was made by 37.9% of the children who consider that vaccine is used to eliminate micro-organisms or diseases by attacking them directly *'kills microbes inside the body'*; *'this*

stops germs developing into diseases'. Some children consider that vaccine is akin to other forms of medication such as antibiotics *'jab can make you feel better it's got good micro's in'*, whilst others simply thought that the vaccine itself acts to cure a disease *'cures diseases and illnesses*'. Both of these groups of children consider that vaccine is reactive rather than preventative and would be administered to cure an existing illness or microbial infection in a similar manner to antibiotics.

In some responses, children (scores 3 and 4) indicated an understanding that micro-organisms are employed in the manufacture of vaccine, *'gets rid of germs in your body so it is a good sort of micro-organism*'. The presence of (beneficial) micro-organisms appears to be sufficient to prevent a disease or eliminate pathogenic micro-organisms *'vaccinations have lots of micro-organism to make or prevent a child from dying or catching disease'*; *'good germs trying to get rid of bad germs*'. It is the micro-organisms *per se* that seem to be the active agent in this process rather than them triggering an immune response in the recipient. However, two children's comments indicate more sophisticated ideas about vaccine manufacture and its effect *'vaccinations are harmless microbes'*; *'this is to prevent bad organisms, sometimes micro-organisms are put into the body to prevent illnesses'*.

Alternative explanations were offered by 7.1% of this age group. For example, a small number (3) of the children in this group seemed to be confused with the notion of contamination resulting from injections or needle use, *'because someone can carry germs and then be injected so then the injecting stick is infected'*. Other children offered

explanations about drugs containing micro-organisms, *'drugs have micro-organisms in them'*. It may be that these children have connected messages from health education about drug use and sharing needles with the photograph of the girl being vaccinated.

- **Antibiotics**

A total of 58.0% of the children (scores 2 and 3) chose the picture of antibiotics and made an association between antibiotics and micro-organisms. The largest number of responses (39.1%) suggested that antibiotics are used as anti-microbial or anti-disease agents, and are used to cure illness or disease, making the connection with the picture of the sick child *'the baby is ill so he needs to take antibiotics (or a vaccination) like the girl'*. The responses from this group of children indicate a prevalent notion of antibiotics as a universal cure *'this baby needs to take antibiotics to get rid of all of the viruses'; 'because antibiotics can cure illnesses'*.

A further 18.9% recognise the use of micro-organisms in the manufacture of antibiotics, with some suggesting that they are, 'good' or 'helpful'. Antibiotic specificity is not mentioned and statements suggest that any 'good' micro-organism will have a positive effect in eliminating any 'bad' micro-organism and that antibiotics will be effective on any illness *'antibiotics is a good source of micro-organisms which fights the bad germs in your body'; 'antibiotics have good bacteria helping illnesses from people such as the sick child'*. The comments also suggest that micro-organisms are the active agents and that antibiotics actually contain micro-organisms that attack the pathogens causing disease *'got good fighting bacteria'; 'micro-organisms to fight bad micro-organisms'*. 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.

- **Bleach**

Figure 2 shows that over half of the children (54.4%) either did not chose the picture of bleach or did not make a connecting statement indicating that they are not aware of the connection with micro-organisms. 23.7% of the cohort gave alternative ideas relating bleach to micro-organisms, suggesting that i) bleach contains micro-organisms to remove or kill harmful micro-organisms ‘*it is a nice germ and kills other bad germs*’ and ii) 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*’.

Sixteen percent of the children suggested that bleach can kill or prevent micro-organisms and were linked to vaccine and antibiotics. Statements, such as ‘*kill germs*’; ‘*prevents microbes*’, suggest that children consider that all three are antimicrobial agents but the mechanisms by which they work is not explored further. Some children indicated that the bleach kills only harmful microbes rather than all micro-organisms ‘*the bleach is used to kill harmful bacteria*’; ‘*it kills bacteria which can cause disease*’, and there seems to be an assumption that the removal is absolute/permanent. It is possible that adverts on television may have influenced these ideas.

It would seem that everyday experiences of being ill and subsequent recovery could be used to develop ideas about disease, infection control and the immune response. Acquired immunity, as well as the difference between antibiotics and vaccines could be

explored at a time when children are receiving vaccinations as it is likely that the ideas would have more meaning at this point. Using television adverts could be exploited to promote debate about anti- microbial products and their efficacy.

Eliciting children's ideas: applications of microbial activity in traditional food technology and medicine

The applications of microbial activity in traditional food technologies or medicine are not generally recognised by the majority of children in this study.

INSERT FIGURE 5 ABOUT HERE

- **Traditional food technology (photographs of bread, beer and yogurt)**

Figure 5 indicates that the responses (scores 2, 3 and 4) for the photographs of the bread, beer and yogurt are similar, with very few children making any positive connection between the photographs of the bread (20.2%), beer (25.5%) and yogurt (26.1%) and micro-organisms. It is surprising that the photograph of the bread was the least selected, as it might be expected that children would have had more experience, especially at a practical level of bread production rather than of beer or yogurt. The results do seem to confirm that children are very unsure about the application of micro-organisms in these traditional technologies. The influence of advertising is evident in children's ideas about beneficial micro-organisms, especially in relation to yogurt '*because some things are made out of good microbes*'; '*useful micro-organisms are used in the yogurt to make it*'; '*because it is made out of harmless microbes*'.

A minority of children cited yeast as the micro-organism used in bread (11.5%) and beer (11.9%) production '*made with the microbe yeast*'; '*yeast is a microbe used in bread and beer*'. Very few children expressed ideas about the way that the metabolic activities of yeast that are capitalised on in bread or beer manufacture, although these children were aware that yeast was necessary to make the bread rise '*because it has yeast which it needs to rise*', or produce alcohol '*makes alcohol*', or carbon dioxide in beer '*because there's yeast in it to make it fizz*'. Whilst more complex ideas would not be expected at 11 years of age, the fact that so few children understand the use of yeast in bread and beer manufacture is not conducive for further learning about more sophisticated concepts of microbial metabolism.

Yeast was the only micro-organism named specifically in connection with food manufacture, including the manufacture of yogurt '*yeast is a microbe, yeast makes bread, beer and yogurt*', suggesting that yeast is regarded as the 'universal' micro-organism used in food production. This is not surprising as yeast is probably the only example that children of this age will have had any experience of, particularly in school and especially in relation to practical work.

The connection between food spoilage, rather than production, and micro-organisms was apparent suggesting that micro-organisms contaminate the food '*bread is fine until it goes mouldy*'; '*this bread is fresh so you won't get ill if you eat it*'; '*it [yogurt] is mouldy because of micro-organisms*'; '*the beer could have someone else's micro-organisms on it*'.

- **Vaccination and antibiotics**

Figure 5 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'*; *'antibiotics contain good micro-organisms to help people get well, vaccinations and antibiotics are similar because they help people get well'*. However, only two children (1.2%) provided information about the production of vaccine, *'vaccinations are harmless microbes that cure diseases inside humans'*. 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'*.

Opportunities for children to engage with more practical work, for example, making yogurt, ginger beer, exploring the conditions for required for yeast to grow, as well as researching the very wide range of food and other products that exploit microbial metabolism may help to develop children's ideas about the application of micro-organisms.

Eliciting children's ideas: decay and cycling of matter and environmental applications

The results from the photographs of the mouldy bread, sour milk, compost heap and sewage works indicate (Figure 6) that children are more aware of the connections between micro-organisms and food decay compared to composting. Connections with micro-organisms and sewage works are primarily linked to the presence of micro-organisms as harmful and a threat to human health.

INSERT FIGURE 6 ABOUT HERE

- **Decay and cycling of matter (mouldy bread, sour milk, compost heap)**

The pattern of responses for mouldy bread and sour milk is similar indicating commonly held ideas about food decay whilst fewer children seem to be aware of the relationship between micro-organisms and composting. Additionally, many more children seem to be aware of the association with micro-organisms and food spoilage compared to their beneficial application in food production.

Children made links (scores 2, 3 and 4) between micro-organisms and photographs of mouldy bread (60.8%), and sour milk (43.8%), indicating that fewer children seem to understand the relationship between micro-organisms and the souring of milk, than micro-organisms and bread going mouldy. Ontological knowledge and everyday experience may help to explain these differences; mouldy bread is visually very obvious and children may have seen and noticed mouldy bread more frequently than sour milk. A small proportion (4.1%) of the children know that the bread is used by micro-organisms

as a substrate and that they grow and multiply within the bread, but only 1.2% offered more advanced ideas about microbial activity causing the milk to become sour.

In contrast, Figure 6 shows that a minority of children (21.9% with scores of 2, 3 and 4) are aware of the relationship between micro-organisms and the compost heap. Statements indicating that micro-organisms were the cause of decay or rotting were made by 8.9% of the children, for example *'mud and dead plants are decayed by micro-organisms; 'micro-organisms help to break down waste'*. Two children were able to add that this is a beneficial activity *'[micro-organisms] are existing in and it goes on to a garden to produce plants'; 'the compost [contains] good bacteria to make healthy food in'*, indicating a simple level of understanding about the cycling of matter. It is surprising that so few children seem to know that micro-organisms break down organic matter even at this basic level, although one child added pictures of leaves and a skeleton and made statements that suggest an understanding of the decay process to some extent *'microbes make things rot, the flesh has rotted because of microbes'*. However, he did not consider that the skeleton would rot, this again is likely to be due to everyday experience, for example pictures in books, television images and so on of skeletons left in graves.

The largest number of responses suggest that micro-organisms are present because the item is rotting *'micro-orgs like gone off things'; 'its mouldy so micro-organisms are in there'; 'the sour milk has micro-organisms in it'*, rather than as the causal factor of decay. Some children also associated the presence of micro-organisms in the compost heap with rubbish and dirt *'has lots of germs from the germs on mouldy food'; 'got germs*

from the rubbish’; *‘mouldy things go in there which causes germs’*; *‘a good place for micro-organisms dirt and germs in it’*. Negative ideas about micro-organisms also feature in the alternative ideas made by children about the compost heap, 7.1% suggest that it is dirty, unhygienic and potentially a dangerous place because of micro-organisms, *‘could spread germs’*; *‘full of bad micro-organisms’*; *‘it’s a dirty place and micro-organisms like dirty places’*; *‘bad micro-organisms live in here’*. These comments indicate that children think, at best, that compost heaps are not useful and that they could even be dangerous by posing a threat to human health.

Similarly sour milk and mouldy bread were associated with illness by 8.9% and 10.7% of children respectively *‘it is a bad source of micro-organisms because it causes diseases’*; *‘bad micro-organisms when it goes it can make you ill’*, and some connected the photographs to the sick child suggesting that they were the cause of his/her illness. These comments suggest unfavourable views about micro-organisms as well as naïve ideas about disease transmission.

Alternative ideas included that the milk and bread, were simply old or out of date: *‘because it has gone stale and out of date’*. 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.

- **Environmental applications (compost heap and sewage works)**

A similar pattern of responses (Figure 6) for the photograph of the sewage works emerged compared to those for the compost heap. 31.0% of the children made a

comment that suggested some connection between the sewage works and micro-organisms, whilst just over half of the children (52.7%) did not choose the picture or made no connecting statement. Microbial activities that were beneficial to the environment were limited to comments about the compost heap and this was considered at the simple level of enriching the soil.

Figure 6 shows the responses made by this age group to the photograph of the sewage works. Only three children (1.8%) stated 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'*. A further 3.0% were aware that harmful micro-organisms were removed from the water *'they process waste with germs in'*. The low level of response suggests 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.

Micro-organisms were associated with sewage works by 26.0% of the children, 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'*; *'gets germs from where you go to the toilet'*, and the sewage works is thought of as a depository rather than having any further function. Negative ideas about micro-organisms are also presented *'it is full of gross waste which has lots of germs'*; *'carries billions of bad germs'*. Dirty and unhygienic conditions associated with the sewage works are attributed to the presence of

micro-organisms *'this has got quite a lot of germs because it's dirty and everything'; 'its dirty water so there's micro-organisms in there'.*

The ideas discussed here indicate that children are unaware of the beneficial microbial activities in decay, cycling of matter, or their use in such everyday application as a sewage farm. Negative ideas about micro-organisms predominate and learning opportunities such as visits to water treatment works, making a compost heap and exploring what happens may help to redress the balance.

Conclusion

The concept mapping technique using photographic associations (CoMPAT) used in this research enabled every child in this study to express their ideas about microbial activity. The photographs stimulated a response and helped to elicit children's ideas, although some photographs seemed to be more effective in producing responses than others. This may be due to the children's understanding of the concepts inherent within the photograph, and thus responses provide a direct measure of children's level of understanding of particular concepts associated with microbial activity. This would seem to be the case as those photographs that were used less frequently had a higher proportion of alternative statements associated with them indicating that these concepts were relatively less well understood by the children in this study.

The photographs were deliberately chosen to have a generic appearance. Some responses indicated that advertising and everyday experiences affect children's ideas. Further

research using photographs of well know brands would provide comparative information and may elicit more productive responses for some of the concepts explored in this study.

The maps produced showed that some children have more complex conceptual frameworks about microbial activity than others. However, the connections that were made tended to be within closely related conceptual domains and it would seem that these children have been taught specific and discrete ideas about micro-organisms. It is incumbent upon curriculum developers and teachers to help children develop their ideas further by providing a more holistic approach to learning, as well as offering more diverse learning opportunities. Data obtained from CoMPAT indicate that detrimental aspects of microbial activity dominate the children's ideas. The eleven year-olds in this study are much more aware of the connections between micro-organisms and disease or food spoilage than of their beneficial activities in food production, medicine or cycling of matter. It is of concern that children are not aware of these aspects of microbial activity; an understanding of these simple applications would not only form the basis for learning about more sophisticated microbial technology and biotechnology, but it might help to redress the balance of predominantly negative perceptions about micro-organisms. The curriculum needs to provide learning opportunities that offer a more balanced view of micro-organisms.

Responses indicate that many alternative ideas or partial understanding exist in all of the areas explored. Many of these ideas suggest ontological thinking and seem to have been gained from everyday experience rather than as a result of teaching. Making use of these

everyday experiences in teaching will have meaning for children and may help them to begin to reconstruct their ideas. However, it is encouraging to note that a small percentage of children did express more sophisticated ideas for each photograph, indicating that eleven year-olds are quite capable of understanding the science related to these concepts of microbial activity. Further work exploring the nature of children's understanding of micro-organisms and how this develops is needed. CoMPAT may be a helpful tool to use in a longitudinal or cross –age study.

The photographs are a visual stimulus and this provides a new way of perceiving concepts about microbial activity that is accessible to all, and may be especially appealing to visual learners. It is also potentially beneficial to those children for whom language or reading ability may provide a stumbling block to completing a more conventional concept map. CoMPAT is therefore a useful addition to the ever increasing ways of concept mapping. It is thought that this technique could be applied equally well to other age groups, as the visual nature of the concepts represented would be understood by both older and younger children.

CoMPAT allowed children to state what they knew about microbial activity, however many of the statements were quite short. Interpretation of the statements and the language the children used was important to ensure the meaning was correctly understood. It would be useful to follow up this data set with in-depth interviews to further explore the children's ideas as this would add a degree of depth and triangulation to the findings presented here.

The children in this study had all completed a short learning sequence about micro-organisms. CoMPAT could be use as a diagnostic exercise pre-teaching, that teachers could employ as a planning tool. After the teaching sequence CoMPAT could then be used as a measure of learning and help to inform teachers what aspects of the topic they need to revisit. Additionally, CoMPAT could be used as a group or whole class exercise to encourage children to develop their ideas together and therefore promote the learning of all. The technique may also have potential in eliciting ideas about other abstract conceptual areas in science, for example, forces, cells, or photosynthesis by enabling children to express their ideas more clearly and to develop their learning.

In summary, this study opened up several avenues of thinking about children's ideas about microbial activity and the implications for the science curriculum. The individual elements of the CoMPAT technique were useful in eliciting children's ideas; quantitative and qualitative data have been obtained from a large number of children across a broad spectrum of ability and reading age. CoMPAT may be a worthwhile additional tool for teachers and researchers to employ in discovering the nature and level of children's knowledge about microbial activity that can be used to benefit learning.

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