



HAL
open science

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

Jenny Byrne, Marcus Grace

► To cite this version:

Jenny Byrne, Marcus Grace. Using a concept mapping tool with a photograph association technique (CoMPAT) to elicit children's ideas about microbial activity. *International Journal of Science Education*, 2010, 32 (04), pp.479-500. 10.1080/09500690802688071 . hal-00567814

HAL Id: hal-00567814

<https://hal.science/hal-00567814>

Submitted on 22 Feb 2011

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



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

Journal:	<i>International Journal of Science Education</i>
Manuscript ID:	TSED-2008-0131.R2
Manuscript Type:	Research Paper
Keywords:	biology education, conceptual development, learning, primary school
Keywords (user):	



1
2
3 **Using a concept mapping tool with a photograph association technique (CoMPAT)**
4
5 **to elicit children's ideas about microbial activity**
6
7

8 **Abstract**
9

10 Concept mapping is a technique used to provide a visual representation of an individual's
11 ideas about a concept or set of related concepts. This paper describes a concept mapping
12 tool using a photograph association technique (CoMPAT) that is considered to be a novel
13 way of eliciting children's ideas. What children at 11 years of age know about particular
14 concepts related to microbial activity is presented and discussed in relation to the
15 effectiveness of CoMPAT as a tool to draw out their ideas. It is proposed that this tool
16 could be used to explore ideas about this and other science concepts from children in
17 other age groups, and where language may be a barrier to participation.
18
19
20
21
22
23
24
25
26
27
28

29 **Introduction**
30

31 Since their inception in the early 1970s, concept mapping techniques and their uses has
32 continued to evolve (Novak & Cañas, 2007). This paper presents a new concept mapping
33 technique that is part of that tradition and demonstrates the adaptability that makes
34 concept mapping a useful way of collecting information about individuals' ideas.
35 Because concept mapping is a flexible tool it can be tailored for use by almost any group
36 of learners (Kinchin, 2000a). The challenge within the context of this research was to
37 design a tool that would be accessible to, and manageable by all the children in the age
38 group. Conventional concept maps require reading skills likely to be beyond some of the
39 children in this study, including those for whom English is not their first language. A
40 new technique, concept mapping using a photograph association technique (CoMPAT)
41 was developed to accommodate these issues in order to be able to work productively with
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 a large number of children within a broad spectrum of reading ages. Photographs
4 providing visual stimuli that were representative of specific concepts associated with
5 microbial activity were employed. Using photographs rather than relying on words alone
6 enabled all of the children in the sample to participate and produce their own concept
7 map. Microbial activity encompasses some complex and abstract concepts. The
8 difficulty of understanding abstract biological concepts has been recognised, for example,
9 photosynthesis (Barker, 1995) or cycling of matter (Hellden, 1996) and conventional
10 methods have been used to discover students' ideas. More recently Chang (2007) used
11 an interview combined with a concept mapping approach to discover children's mental
12 models of homeostasis. The purpose of this research was to discover if using
13 photographs as visual stimuli would enable children to create concept maps that could
14 provide an insight about their ideas of microbial activity.
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33

34 Micro-organisms have an essential role in life on Earth and their metabolic activities have
35 been exploited by humans since Babylonian times (Black, 2005). The manipulation of
36 their genomes in ever more developing biotechnologies and their use in fields as diverse
37 as medicine, mining and environmental remediation makes microbiology an increasingly
38 important area of science that impacts on everyday life. However, there are few
39 opportunities within the primary curriculum, in England, for learning about micro-
40 organisms. This state of affairs provided the impetus for the research, as it seems
41 essential to find out what children know and understand about microbial activities and
42 related biotechnologies prior to further teaching (Dawson, 2003; Lock and Miles, 1993) if
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 they are to engage in meaningful debate about scientific issues (Millar and Osborne,
4
5
6 1998; Reiss, 2002).
7
8
9

10 The focus of the study was concerned with the effectiveness of CoMPAT as a tool to
11
12 elicit children's ideas about microbial activity; as a result the following research
13
14 questions were posed:
15

- 16 • Does the concept mapping technique (CoMPAT) enable children's ideas
17
18 about microbial activity to be elicited?
19
- 20 • What do 11-year-olds know and understand about microbial activity?
21
22
23
24
25
26

27 **Background and theoretical perspective**

28
29 Constructivism is an epistemological theory concerned with the structure and process of
30
31 learning (Bentley, 1998), and it holds that every individual constructs their own ideas
32
33 rather than receiving them complete, whole and accurate from a source of authority
34
35 (Selley, 1999). This research is framed within a constructivist view of learning science,
36
37 which acknowledges that children construct their own knowledge in an active and
38
39 dynamic manner and the ideas that children hold may not equate to scientifically
40
41 accepted warrants and claims (Driver, 1989; Osborne, Wadsworth, & Black, 1992). It
42
43 holds that children acquire ideas, in trying to make sense of scientific phenomena, from a
44
45 variety of sources, including everyday events and situations (Driver, Squires, Rushworth
46
47 & Wood-Robinson, 1994; Newton, Driver, & Osborne, J., 1999; Shepardson, 2002;
48
49 Tobin, 1998). It is, therefore, not surprising to find that children's ideas about many
50
51 scientific phenomena differ from the accepted view, and that these ideas may influence
52
53
54
55
56
57
58
59
60

1
2
3 further learning (Ausubel, 1968). Discovering the ideas that children hold about
4 particular scientific concepts is now considered to be an important aspect of a
5 constructivist approach to learning (Driver, Guesne, E. & Tiberghien, 1985; Osborne &
6 Freyberg, 1985; Scott, 1987).
7
8
9
10
11

12
13
14
15 Concept mapping as a technique to discover the ideas an individual holds about particular
16 concepts is underpinned by a constructivist epistemology (Novak & Gowin, 1984; Novak
17 & Cañas, 2007). Concept maps have been used widely as pedagogical tools for planning,
18 instruction, assessment or evaluation of learning (e.g. Barenholz & Tamir, 1992; Chang,
19 2007; Kinchin, 2000a, 2000b ; Mintzes, Wandersee & Novak, 2000; van Zele, Lenaerts,
20 & Wieme, 2004; Yin, Vanides, Ruiz-Primo). Concept maps are a visual representation of
21 the relationship between different concepts and allow individuals to indicate their
22 understanding of the relationships between ideas, things or people (van Zele *et al.*, 2004;
23 White & Gunstone, 1992). Novak and Gowin (1984), elaborate this point by stating that
24 concept maps allow the content, structure and relations of children's ideas to be explored
25 simultaneously. Concept maps therefore provide an efficient mechanism for eliciting the
26 relationships children may hold about concepts, in this instance, the concepts about
27 microbial activity.
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

48 **Participants**

49
50 The 169 participants in this study were children aged 11 years. **The research set out to**
51 **find out what this age group knew about microbial activity after they had just completed**
52 **a short learning sequence about micro-organisms based on the relevant National**
53
54
55
56
57
58
59
60

1
2
3 Curriculum science programme of study for England (DfES, 1999) and . The children
4
5 were drawn from three separate state schools in and near Southampton and provided a
6
7 sample which was broadly representative of the age group in terms of academic ability,
8
9 socio economic factors, gender and ethnicity.
10
11

12 13 14 15 **The research tool - CoMPAT**

16
17 Photographs provide visual, rather than verbal, prompts that may help to promote the
18
19 elicitation of children's ideas by stimulating different intelligences (Gardner, 1999), and
20
21 are thought to play a crucial role in the learning process (Alesandrini, 1984). The
22
23 photographs were selected to be direct representations or analogies of the key areas of
24
25 microbial activity that this age group is likely to have had some experience of, and they
26
27 are all related to statutory teaching requirements in the English curriculum. Furthermore,
28
29 they were images that had been most frequently selected by children during a previous
30
31 smaller study (Byrne & Sharp, 2006). The photographs provided more examples of
32
33 beneficial than non-beneficial microbial activity, which is more representative of reality,
34
35 and tried to avoid well known brands that may have elicited a skewed response. An
36
37 expert map, in which the most important links are presented, was not created to judge the
38
39 maps produced by the children, as this was deemed unnecessary for the purposes of the
40
41 study.
42
43
44
45
46
47
48
49
50

51 The photographs (Figure 1) are representative of the particular concepts associated with
52
53 the key areas of microbial activity being investigated, for example, the sick child
54
55 represents disease, the bread represents application of micro-organisms in traditional food
56
57
58
59
60

1
2
3 technology, and the mouldy bread represents decay. For this study, the key areas of
4
5 microbial activity and the photographs that represent the concepts are:
6
7

- 8 • disease, infection control and health (sick child, antibiotics, vaccination
9 and bleach);
- 10 • application of micro-organisms in traditional food technology (bread,
11 beer, yogurt) and medication (vaccination and antibiotics);
- 12 • decay and cycling of matter (mouldy bread, sour milk, compost heap,
13 sewage works) and environmental applications (compost heap and
14 sewage works).

15
16
17
18
19
20
21
22
23
24
25 The photographs were labelled to provide additional information to clarify what the
26
27 photograph represented, in order to avoid misinterpretation, and to assist those children
28
29 who prefer the written word rather than a picture. Children were allowed to ask what the
30
31 label said, although they were given no further information. Two terms ‘micro-organism’
32
33 and ‘germ’ were also provided because some children in the earlier study by Byrne and
34
35 Sharp were unfamiliar with the term micro-organism whilst others used both terms, often
36
37 interchangeably.
38
39
40
41
42

43
44 Each child was given a sheet of named photographs and they were asked to select the
45
46 photographs that they considered had any connection with micro-organisms. The
47
48 children used the chosen photographs to produce their concept maps by cutting them out
49
50 and sticking them onto a sheet of A3 paper on which they had already placed the term
51
52 ‘micro-organism’ or ‘germ’. They were asked to draw lines between the photograph and
53
54 the term and state the connection between the photograph and the term. They were
55
56
57
58
59
60

1
2
3 encouraged to think of all the connections they could as some photographs have a number
4 of inherent sub-concepts. The children were also asked to make connections between the
5 different photographs and to add any additional ideas if they could. These instructions
6 were given so that the completed maps would represent the level of complexity of the
7 children's conceptual frameworks regarding microbial activity. The children were told
8 that this was not a test and that they should state everything they could whilst it was
9 expected that they would work alone and not share their ideas with anyone else. The
10 research was conducted in the children's normal classroom environment and they were
11 given as much time as they needed to complete their maps.
12
13
14
15
16
17
18
19
20
21
22
23

24 **INSERT FIGURE 1 ABOUT HERE**

25 **Assessing the concept maps**

26
27 The photograph concept maps produced by the children were analysed qualitatively and
28 quantitatively. van Zele *et al.* (2004), note that a qualitative analysis of concept maps
29 produced by university students studying physics provided a more informative and
30 holistic picture of their understanding compared to quantitatively scoring the maps. The
31 maps were categorised according to the concept map structures, identified by Kinchin,
32 Hay & Adams (2000) that indicate the level of complexity of the mental model held by an
33 individual. These are, 'Spoke' in which all aspects of the topic are related directly to the
34 key concept only, 'Chain' in which each concept is linked to another in a linear fashion,
35 and 'Net' in which concepts are linked in an integrated network.
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51
52 The linking statements, known as propositions, (Novak & Gowin, 1984) between
53 concepts also indicate the level and complexity of understanding and this was also
54 employed in the analysis of the data. The propositions that children used with each
55
56
57
58
59
60

1
2
3 photograph were therefore assigned to a particular category. These propositions were
4
5 further categorised and assigned a score. The purpose of this analysis was to provide an
6
7 overview of what children know and understand about micro-organisms, rather than
8
9 provide an assessment score for each individual. White and Gunstone (1992) offer a
10
11 scoring system based on Novak and Gowin's (1984) system that has been adapted for use
12
13 here and includes both qualitative and quantitative approaches, these include:
14
15

- 16 • Recording which photographs were chosen;
- 17
- 18 • Recording all the propositions;
- 19
- 20 • Categorising the propositions;
- 21
- 22 • Recording absence of propositions or photograph;
- 23
- 24
- 25
- 26

27 In addition to scoring the number of propositions, their quality and accuracy were also
28
29 analysed in order provide an insight into the depth of knowledge and understanding
30
31 children have about microbial activity. A scoring system employing a five point scale
32
33 (Table 1) similar to that used by Yin *et al.* (2005), was developed to provide an accuracy
34
35 score for each photograph to determine the level of knowledge and understanding held by
36
37 the 11-year-olds in this study.
38
39

40 41 **INSERT TABLE 1 ABOUT HERE**

42
43 Recent research has explored the reliability and validity of scoring systems (Kinchin
44
45 2000 b; Klein, Chung, Osmundson, Herl, & O'Neil, 2001; McClure, Sonak, & Suen,
46
47 1999), and this research has sought to ensure that the scoring system adopted is both
48
49 reliable and valid. The validity of the categories used to score each photograph was
50
51 discussed with two experts separately. Agreement was reached about the accuracy of the
52
53 scoring of each category for the different photographs. An inter-rater reliability exercise
54
55
56
57
58
59
60

1
2
3 using undertaken on a 15% sample of all the maps and using Cohen's Kappa (Cohen,
4
5 1960) was found to be 0.78, indicating a satisfactory level of reliability. Details of the
6
7 criteria used to score each photograph are presented in Table 2. **The scoring system**
8
9 **specifically included alternative or non-scientific statements as valid contributions**
10
11 **because they are frequently part of children's ideas and should be considered when**
12
13 **developing learning sequences about a topic. In addition, the accuracy of the statements**
14
15 **was not judged in terms of semantics or 'correct' usage of specific terms; instead the**
16
17 **meaning of each statement was interpreted against the criteria.** Frequency and percentage
18
19 data were calculated for each photograph on every map. Table 3 provides a summary of
20
21 the scores obtained.
22
23
24
25

26
27 **INSERT TABLE 2 ABOUT HERE**
28

29 **Results and discussion**

30 **Eliciting children's ideas: use of photographs**

31
32 Some children selected each photograph to produce their concept maps (Table 3). This
33
34 indicates that, for them, the photographs were appropriate representations of the
35
36 microbial activities that they were meant to depict. However it is noticeable that certain
37
38 photographs were not included in the maps by over 50 % of the cohort. This rejection
39
40 may be for two interrelated reasons. Firstly that the children did not know about the
41
42 microbial activity represented in the photograph, secondly that the photograph had no
43
44 meaning for them with respect to microbial activity, i.e. the photograph was not a clear
45
46 enough illustration of the microbial activity it was meant to represent. The latter of these
47
48 explanations would indicate that the microbial activity was less explicit within some
49
50 photographs than others. However the research instructions asked the children to choose
51
52
53
54
55
56
57
58
59
60

1
2
3 the photographs that they thought had anything to do with micro- organisms, and a clear
4 rejection based upon lack of knowledge seems to be a likely explanation. This is also
5 supported by the relatively higher proportion of alternative statements (score1) elicited by
6 these photographs compared to the photographs that were chosen more frequently. **These**
7 **alternative ideas provide a valuable source of information for teachers; by acknowledging**
8 **them and planning lessons taking them into account they can help to develop children's**
9 **ideas that are more congruent with a scientifically accepted view of microbial activity.**

10
11
12
13
14
15
16
17
18
19
20
21
22 It is also noticeable that very few children offered a more advanced idea (score 4) about
23 the microbial activity depicted in the photographs. This is not unexpected since the ideas
24 anticipated at this level are more sophisticated than the taught curriculum requires for this
25 age group. It is therefore interesting that at least some children provided advanced ideas
26 indicating that they had acquired these ideas from somewhere other than school. **This**
27 **everyday knowledge could be exploited by teachers to provide more personalised**
28 **learning and therefore more meaningful and richer experiences for these children.**

29
30
31
32
33
34
35
36
37
38 **INSERT TABLE 3 ABOUT HERE**

39 40 41 **Eliciting children's ideas: map structure**

42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
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

1
2
3 they cause decay *'it's been made mouldy by them'*. He has an appreciation of both some
4
5 of the positive and negative aspects of microbial activity but the information he provides
6
7 about each photograph is fairly basic, and there are no connections made between the
8
9 photographs. Tom appears to know specific discrete facts about microbial activity but he
10
11 has not related any of these to each other. Tom's map also illustrates some non-scientific
12
13 ideas that were commonly held, about bleach *'it uses microbes for cleaning'*, and about
14
15 milk *'it is made with and contains microbes'*.
16
17
18

19
20 INSERT FIGURE 2 ABOUT HERE
21

22 Concept maps showing a 'Net' structure were presented by 22% of the children. Most of
23
24 the maps were not very complex and had only one or two connections linking
25
26 photographs of closely related concepts. Table 4 shows the type and number of the
27
28 linking propositions made. The commonest connection was between the photographs of
29
30 antibiotics and/ or vaccination with the sick child. *'Antibiotics and vaccinations help*
31
32 *stop sickness'* is a typical statement; this is not surprising as children of this age will
33
34 probably have experienced both antibiotics and vaccinations.
35
36
37

38
39 INSERT TABLE 4 ABOUT HERE
40

41 Jane's map (Figure 3) shows three linking statements that are amongst the commonest
42
43 elicited by the whole cohort; vaccination and antibiotics as medicines *'some microbes*
44
45 *help you get better, these make you better so they are connected'*, food production
46
47 *'micro-organisms help make yogurt, beer and yeast which is in bread'*, and the mouldy
48
49 and fresh bread *'microbes need the right temperature so here they have put mould on the*
50
51 *bread'*. Jane's linking propositions indicate that she is able to categorise particular
52
53 photographs as representing the same concept. The difference in the complexity of the
54
55
56
57
58
59
60

1
2
3 two maps indicates Jane's understanding of some aspects of microbial activity is more
4 developed that Tom's. Tom seems to have acquired separate facts whilst Jane has begun
5 to collate those facts to form hubs of ideas around closely related concepts. It may be
6 useful to have children produce maps together as a group, rather than as an individual
7 exercise, so that they help each other construct and develop their ideas. Additionally,
8 teachers could scaffold children's ideas by helping them explore connections beyond
9 those expressed by the children here.

10
11
12
13
14
15
16
17
18
19
20 **INSERT FIGURE 3 ABOUT HERE**

21
22 However, Jane's other propositions do not illustrate any greater depth of understanding
23 when compared to Tom's isolated statements, and the rest of the map is more like a
24 'Spoke' structure. Jane also cites the commonly held alternative idea that milk is made
25 using micro-organisms. The understanding illustrated by the propositions is discussed
26 below; this will provide insights into the depth of understanding about microbial activity
27 of the whole cohort.

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

39
40 Children's responses indicate that they have more ideas about this aspect of microbial
41 activity, and that they have fewer non-scientific ideas in comparison to the other
42 microbial activities - with the exception of ideas related to the photograph of bleach. The
43 ideas that children hold are also interconnected, for example, the medical application of
44 vaccines and antibiotics.

45
46
47
48
49
50
51
52 **INSERT FIGURE 4 ABOUT HERE**

- 53
54
55 • **Sick child**

1
2
3 The overall pattern of responses can be seen in Figure 4 and indicates that the majority of
4 children at this age have some notion of the connection between disease and micro-
5 organisms. Although a small number (7.1%) provided alternative (score 1) statements,
6 for example, this ambiguous statement *'the illness the baby has is germs'*. The most
7 common response indicates that this group of children consider micro-organisms to be
8 the causal agent of disease and 26.0% of the children connect the photographs of
9 antibiotics and/ or the vaccination to the sick child as a means to eliminate the micro-
10 organisms *'antibiotics help to kill bad micro-organisms'*; *'gets rid of or prevents*
11 *otherwise you might end up as a sick child'*. Only four children (2.4%) provided more
12 sophisticated ideas, suggesting that the child was ill because of the effect of microbial
13 activity *'the outcome of germs'*; *'micro-organisms have done something to make the child*
14 *ill'*, although their ideas are relatively simple and imprecise and do not express any ideas
15 about immune response. Other responses (24.3%) indicate that the presence of micro-
16 organisms is associated with illness. It would seem that illness is regarded by these
17 children as a result of somehow simply coming into contact with micro-organisms.
18 Direct teaching or everyday experiences is evident in some responses where micro-
19 organisms are referred to as 'bad' because they cause disease.

- **Vaccination**

20 A total of 54.5% of children (scores 2, 3 and 4) used the picture of the vaccination and
21 responses indicate that vaccinations are understood to be related to micro-organisms as a
22 means of eliminating them or the disease that they cause. The most common response
23 was made by 37.9% of the children who consider that vaccine is used to eliminate micro-
24 organisms or diseases by attacking them directly *'kills microbes inside the body'*; *'this*
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 *stops germs developing into diseases*'. Some children consider that vaccine is akin to
4
5 other forms of medication such as antibiotics *'jab can make you feel better it's got good*
6
7 *micro's in'*, whilst others simply thought that the vaccine itself acts to cure a disease
8
9 *'cures diseases and illnesses'*. Both of these groups of children consider that vaccine is
10
11 reactive rather than preventative and would be administered to cure an existing illness or
12
13 microbial infection in a similar manner to antibiotics.
14
15
16
17
18
19

20 In some responses, children (scores 3 and 4) indicated an understanding that micro-
21
22 organisms are employed in the manufacture of vaccine, *'gets rid of germs in your body so*
23
24 *it is a good sort of micro-organism'*. The presence of (beneficial) micro-organisms
25
26 appears to be sufficient to prevent a disease or eliminate pathogenic micro-organisms
27
28 *'vaccinations have lots of micro-organism to make or prevent a child from dying or*
29
30 *catching disease'*; *'good germs trying to get rid of bad germs'*. It is the micro-organisms
31
32 *per se* that seem to be the active agent in this process rather than them triggering an
33
34 immune response in the recipient. However, two children's comments indicate more
35
36 sophisticated ideas about vaccine manufacture and its effect *'vaccinations are harmless*
37
38 *microbes'*; *'this is to prevent bad organisms, sometimes micro-organisms are put into the*
39
40 *body to prevent illnesses'*.
41
42
43
44
45
46
47

48 Alternative explanations were offered by 7.1% of this age group. For example, a small
49
50 number (3) of the children in this group seemed to be confused with the notion of
51
52 contamination resulting from injections or needle use, *'because someone can carry germs*
53
54 *and then be injected so then the injecting stick is infected'*. Other children offered
55
56
57
58
59
60

1
2
3 explanations about drugs containing micro-organisms, *'drugs have micro-organisms in*
4 *them'*. It may be that these children have connected messages from health education
5
6 about drug use and sharing needles with the photograph of the girl being vaccinated.
7
8
9

10
11 • **Antibiotics**

12 A total of 58.0% of the children (scores 2 and 3) chose the picture of antibiotics and made
13 an association between antibiotics and micro-organisms. The largest number of
14 responses (39.1%) suggested that antibiotics are used as anti-microbial or anti-disease
15 agents, and are used to cure illness or disease, making the connection with the picture of
16 the sick child *'the baby is ill so he needs to take antibiotics (or a vaccination) like the*
17 *girl'*. The responses from this group of children indicate a prevalent notion of antibiotics
18 as a universal cure *'this baby needs to take antibiotics to get rid of all of the viruses';*
19 *'because antibiotics can cure illnesses'*.
20
21
22
23
24
25
26
27
28
29
30

31 A further 18.9% recognise the use of micro-organisms in the manufacture of antibiotics,
32 with some suggesting that they are, 'good' or 'helpful'. Antibiotic specificity is not
33 mentioned and statements suggest that any 'good' micro-organism will have a positive
34 effect in eliminating any 'bad' micro-organism and that antibiotics will be effective on
35 any illness *'antibiotics is a good source of micro-organisms which fights the bad germs*
36 *in your body'; 'antibiotics have good bacteria helping illnesses from people such as the*
37 *sick child'*. The comments also suggest that micro-organisms are the active agents and
38 that antibiotics actually contain micro-organisms that attack the pathogens causing
39 disease *'got good fighting bacteria'; 'micro-organisms to fight bad micro-organisms'*.
40
41
42
43
44
45
46
47
48
49
50
51
52

53 The language used is aggressive and confrontational which suggests that the children
54
55
56
57
58
59
60

1
2
3 consider that a pitched battle is taking place between the ‘good’ and ‘bad’ micro-
4
5 organisms.
6

7
8 • **Bleach**
9

10 Figure 2 shows that over half of the children (54.4%) either did not chose the picture of
11 bleach or did not make a connecting statement indicating that they are not aware of the
12 connection with micro-organisms. 23.7% of the cohort gave alternative ideas relating
13 bleach to micro-organisms, suggesting that i) bleach contains micro-organisms to remove
14 or kill harmful micro-organisms ‘*it is a nice germ and kills other bad germs*’ and ii) that
15 they were present in the bleach as a cleansing agent, in this case attributing almost
16 magical properties ‘*bleach contains germs to make the room clean and tidy*’.
17
18
19
20
21
22
23
24
25
26
27

28
29 Sixteen percent of the children suggested that bleach can kill or prevent micro-organisms
30 and were linked to vaccine and antibiotics. Statements, such as ‘*kill germs*’; ‘*prevents*
31 *microbes*’, suggest that children consider that all three are antimicrobial agents but the
32 mechanisms by which they work is not explored further. Some children indicated that
33 the bleach kills only harmful microbes rather than all micro-organisms ‘*the bleach is used*
34 *to kill harmful bacteria*’; ‘*it kills bacteria which can cause disease*’, and there seems to
35 be an assumption that the removal is absolute/permanent. It is possible that adverts on
36 television may have influenced these ideas.
37
38
39
40
41
42
43
44
45
46
47
48
49

50 It would seem that everyday experiences of being ill and subsequent recovery could be
51 used to develop ideas about disease, infection control and the immune response.
52
53 Acquired immunity, as well as the difference between antibiotics and vaccines could be
54
55
56
57
58
59
60

1
2
3 explored at a time when children are receiving vaccinations as it is likely that the ideas
4 would have more meaning at this point. Using television adverts could be exploited to
5 promote debate about anti- microbial products and their efficacy.
6
7
8
9

10 11 12 **Eliciting children's ideas: applications of microbial activity in traditional food** 13 **technology and medicine** 14

15
16
17 The applications of microbial activity in traditional food technologies or medicine are not
18 generally recognised by the majority of children in this study.
19

20 21 **INSERT FIGURE 5 ABOUT HERE** 22

- 23
24
25 • **Traditional food technology (photographs of bread, beer and yogurt)**
26

27 Figure 5 indicates that the responses (scores 2, 3 and 4) for the photographs of the bread,
28 beer and yogurt are similar, with very few children making any positive connection
29 between the photographs of the bread (20.2%), beer (25.5%) and yogurt (26.1%) and
30 micro-organisms. It is surprising that the photograph of the bread was the least selected,
31 as it might be expected that children would have had more experience, especially at a
32 practical level of bread production rather than of beer or yogurt. The results do seem to
33 confirm that children are very unsure about the application of micro-organisms in these
34 traditional technologies. The influence of advertising is evident in children's ideas about
35 beneficial micro-organisms, especially in relation to yogurt '*because some things are*
36 '*made out of good microbes*'; '*useful micro-organisms are used in the yogurt to make it*';
37 '*because it is made out of harmless microbes*'.
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 A minority of children cited yeast as the micro-organism used in bread (11.5%) and beer
4 (11.9%) production '*made with the microbe yeast*'; '*yeast is a microbe used in bread and*
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

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

1
2
3 as a substrate and that they grow and multiply within the bread, but only 1.2% offered
4
5 more advanced ideas about microbial activity causing the milk to become sour.
6
7

8
9
10 In contrast, Figure 6 shows that a minority of children (21.9% with scores of 2, 3 and 4)
11
12 are aware of the relationship between micro-organisms and the compost heap.
13
14 Statements indicating that micro-organisms were the cause of decay or rotting were made
15
16 by 8.9% of the children, for example *'mud and dead plants are decayed by micro-*
17
18 *organisms; 'micro-organisms help to break down waste'*. Two children were able to add
19
20 that this is a beneficial activity *'[micro-organisms] are existing in and it goes on to a*
21
22 *garden to produce plants'; 'the compost [contains] good bacteria to make healthy food*
23
24 *in'*, indicating a simple level of understanding about the cycling of matter. It is surprising
25
26 that so few children seem to know that micro-organisms break down organic matter even
27
28 at this basic level, although one child added pictures of leaves and a skeleton and made
29
30 statements that suggest an understanding of the decay process to some extent *'microbes*
31
32 *make things rot, the flesh has rotted because of microbes'*. However, he did not consider
33
34 that the skeleton would rot, this again is likely to be due to everyday experience, for
35
36 example pictures in books, television images and so on of skeletons left in graves.
37
38
39
40
41
42
43
44
45

46 The largest number of responses suggest that micro-organisms are present because the
47
48 item is rotting *'micro-orgs like gone off things'; 'its mouldy so micro-organisms are in*
49
50 *there'; 'the sour milk has micro-organisms in it'*, rather than as the causal factor of
51
52 decay. Some children also associated the presence of micro-organisms in the compost
53
54 heap with rubbish and dirt *'has lots of germs from the germs on mouldy food'; 'got germs*
55
56
57
58
59
60

1
2
3 *from the rubbish*’; *‘mouldy things go in there which causes germs*’; *‘a good place for*
4 *micro-organisms dirt and germs in it*’. Negative ideas about micro-organisms also
5
6
7
8 feature in the alternative ideas made by children about the compost heap, 7.1% suggest
9
10 that it is dirty, unhygienic and potentially a dangerous place because of micro-organisms,
11
12 *‘could spread germs*’; *‘full of bad micro-organisms*’; *‘it’s a dirty place and micro-*
13 *organisms like dirty places*’; *‘bad micro-organisms live in here*’. These comments
14
15 indicate that children think, at best, that compost heaps are not useful and that they could
16
17
18 even be dangerous by posing a threat to human health.
19
20
21

22
23
24 Similarly sour milk and mouldy bread were associated with illness by 8.9% and 10.7% of
25
26 children respectively *‘it is a bad source of micro-organisms because it causes diseases*’;
27
28 *‘bad micro-organisms when it goes it can make you ill*’, and some connected the
29
30 photographs to the sick child suggesting that they were the cause of his/her illness. These
31
32 comments suggest unfavourable views about micro-organisms as well as naïve ideas
33
34 about disease transmission.
35
36
37

38
39
40 Alternative ideas included that the milk and bread, were simply old or out of date:
41
42 *‘because it has gone stale and out of date*’. Sell by dates are a prevalent part of
43
44 children’s everyday awareness of food and it is not surprising that some children made
45
46 this type of response.
47
48
49

50
51 • **Environmental applications (compost heap and sewage works)**
52

53 A similar pattern of responses (Figure 6) for the photograph of the sewage works
54
55 emerged compared to those for the compost heap. 31.0% of the children made a
56
57
58
59
60

1
2
3 comment that suggested some connection between the sewage works and micro-
4 organisms, whilst just over half of the children (52.7%) did not choose the picture or
5 made no connecting statement. Microbial activities that were beneficial to the
6 environment were limited to comments about the compost heap and this was considered
7 at the simple level of enriching the soil.
8

9
10
11
12
13
14
15 Figure 6 shows the responses made by this age group to the photograph of the sewage
16 works. Only three children (1.8%) stated that micro-organisms break down waste
17 products (organic matter) in response to the photograph of the sewage works '*both*
18 *sewage and compost are broken down by microbes*'. A further 3.0% were aware that
19 harmful micro-organisms were removed from the water '*they process waste with germs*
20 *in*'. The low level of response suggests that whilst children are able to comprehend the
21 principles behind what happens in sewage works they are neither taught in school, nor
22 know through their everyday experiences about the function of micro-organisms in
23 sewage works.
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38

39 Micro-organisms were associated with sewage works by 26.0% of the children, although
40 their ideas were limited and many of the comments indicate a connection with human
41 excreta '*sewage is a prime place for germs as it is full of poo*'; '*gets germs from where*
42 *you go to the toilet*', and the sewage works is thought of as a depository rather than
43 having any further function. Negative ideas about micro-organisms are also presented '*it*
44 *is full of gross waste which has lots of germs*'; '*carries billions of bad germs*'. Dirty and
45 unhygienic conditions associated with the sewage works are attributed to the presence of
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

1
2
3 micro-organisms *'this has got quite a lot of germs because it's dirty and everything'*; *'its*
4
5 *dirty water so there's micro-organisms in there'*.
6
7
8
9

10 The ideas discussed here indicate that children are unaware of the beneficial microbial
11 activities in decay, cycling of matter, or their use in such everyday application as a
12 sewage farm. Negative ideas about micro-organisms predominate and learning
13 opportunities such as visits to water treatment works, making a compost heap and
14 exploring what happens may help to redress the balance.
15
16
17
18
19
20
21

22 **Conclusion**

23
24 The concept mapping technique using photographic associations (CoMPAT) used in this
25 research enabled every child in this study to express their ideas about microbial activity.
26
27

28 The photographs stimulated a response and helped to elicit children's ideas, although
29 some photographs seemed to be more effective in producing responses than others. This
30 may be due to the children's understanding of the concepts inherent within the
31 photograph, and thus responses provide a direct measure of children's level of
32 understanding of particular concepts associated with microbial activity. This would seem
33 to be the case as those photographs that were used less frequently had a higher proportion
34 of alternative statements associated with them indicating that these concepts were
35 relatively less well understood by the children in this study.
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50

51 The photographs were deliberately chosen to have a generic appearance. Some responses
52 indicated that advertising and everyday experiences affect children's ideas. Further
53
54
55
56
57
58
59
60

1
2
3 research using photographs of well know brands would provide comparative information
4
5 and may elicit more productive responses for some of the concepts explored in this study.
6
7

8
9
10 The maps produced showed that some children have more complex conceptual
11
12 frameworks about microbial activity than others. However, the connections that were
13
14 made tended to be within closely related conceptual domains and it would seem that these
15
16 children have been taught specific and discrete ideas about micro-organisms. It is
17
18 incumbent upon curriculum developers and teachers to help children develop their ideas
19
20 further by providing a more holistic approach to learning, as well as offering more
21
22 diverse learning opportunities. Data obtained from CoMPAT indicate that detrimental
23
24 aspects of microbial activity dominate the children's ideas. The eleven year-olds in this
25
26 study are much more aware of the connections between micro-organisms and disease or
27
28 food spoilage than of their beneficial activities in food production, medicine or cycling of
29
30 matter. It is of concern that children are not aware of these aspects of microbial activity;
31
32 an understanding of these simple applications would not only form the basis for learning
33
34 about more sophisticated microbial technology and biotechnology, but it might help to
35
36 redress the balance of predominantly negative perceptions about micro-organisms. The
37
38 curriculum needs to provide learning opportunities that offer a more balanced view of
39
40 micro-organisms.
41
42
43
44
45
46
47
48
49

50 Responses indicate that many alternative ideas or partial understanding exist in all of the
51
52 areas explored. Many of these ideas suggest ontological thinking and seem to have been
53
54 gained from everyday experience rather than as a result of teaching. Making use of these
55
56
57
58
59
60

1
2
3 everyday experiences in teaching will have meaning for children and may help them to
4
5 begin to reconstruct their ideas. However, it is encouraging to note that a small
6
7 percentage of children did express more sophisticated ideas for each photograph,
8
9 indicating that eleven year-olds are quite capable of understanding the science related to
10
11 these concepts of microbial activity. Further work exploring the nature of children's
12
13 understanding of micro-organisms and how this develops is needed. CoMPAT may be a
14
15 helpful tool to use in a longitudinal or cross –age study.
16
17
18
19

20
21
22 The photographs are a visual stimulus and this provides a new way of perceiving
23
24 concepts about microbial activity that is accessible to all, and may be especially
25
26 appealing to visual learners. It is also potentially beneficial to those children for whom
27
28 language or reading ability may provide a stumbling block to completing a more
29
30 conventional concept map. CoMPAT is therefore a useful addition to the ever increasing
31
32 ways of concept mapping. It is thought that this technique could be applied equally well
33
34 to other age groups, as the visual nature of the concepts represented would be understood
35
36 by both older and younger children.
37
38
39
40

41
42
43 CoMPAT allowed children to state what they knew about microbial activity, however
44
45 many of the statements were quite short. Interpretation of the statements and the
46
47 language the children used was important to ensure the meaning was correctly
48
49 understood. It would be useful to follow up this data set with in-depth interviews to
50
51 further explore the children's ideas as this would add a degree of depth and triangulation
52
53 to the findings presented here.
54
55
56
57
58
59
60

1
2
3
4
5
6 The children in this study had all completed a short learning sequence about micro-
7
8 organisms. CoMPAT could be use as a diagnostic exercise pre-teaching, that teachers
9
10 could employ as a planning tool. After the teaching sequence CoMPAT could then be
11
12 used as a measure of learning and help to inform teachers what aspects of the topic they
13
14 need to revisit. Additionally, CoMPAT could be used as a group or whole class exercise
15
16 to encourage children to develop their ideas together and therefore promote the learning
17
18 of all. The technique may also have potential in eliciting ideas about other abstract
19
20 conceptual areas in science, for example, forces, cells, or photosynthesis by enabling
21
22 children to express their ideas more clearly and to develop their learning.
23
24
25
26
27
28

29
30 In summary, this study opened up several avenues of thinking about children's ideas
31
32 about microbial activity and the implications for the science curriculum. The individual
33
34 elements of the CoMPAT technique were useful in eliciting children's ideas; quantitative
35
36 and qualitative data have been obtained from a large number of children across a broad
37
38 spectrum of ability and reading age. CoMPAT may be a worthwhile additional tool for
39
40 teachers and researchers to employ in discovering the nature and level of children's
41
42 knowledge about microbial activity that can be used to benefit learning.
43
44
45

46 **References**

47
48 Alesandrini, K.L. (1984). Pictures and adult learning. *Instructional Science*, 13,
49
50 63-77.
51

52
53 Ausubel, D. P. (1968). *Educational Psychology: a cognitive view*. New York,
54
55 Holt, Rinehart and Winston.
56
57
58
59
60

1
2
3 Barenholz, H. & Tamir, P. (1992). A comprehensive use of concept mapping in
4 design instruction and assessment. *Research in Science and Technological Education*, 10,
5
6 1, 37-52.
7
8

9
10 Barker, M. (1995). A plant is an animal standing on its head. *Journal of*
11
12 *Biological Education*, 29, 30, 201-208.
13

14
15 Bentley, M. L. (1998). Constructivism as a referent for reforming science
16 education. In Larochelle, M., Bednarz, N. & Garrison, J. (Eds.) *Constructivism and*
17
18 *Education* (pp. 233-249). Cambridge, Cambridge University Press.
19

20
21 Black, J. G. (2005). *Microbiology: principles and explorations* (6th edition).
22
23 New York, Wiley Publications.
24

25
26
27 Byrne, J. & Sharp, J. (2006). Children's ideas about micro-organisms. *School*
28
29 *Science Review*, 88, 322, 71-79.
30

31
32 Chang, S. (2007). Externalising students' mental models through concept maps.
33
34 *Journal of Biological Education*, 41, 3, 107-112.
35

36
37 Cohen, J. (1960). A coefficient of agreement for nominal scales. *Educational and*
38
39 *Psychological Measurement*, 20, 37-46.
40

41
42 Dawson, V. (2003). Western Australian school students' understanding of
43
44 biotechnology. *International Journal of Science Education*, 25, 1, 57-69.
45

46
47 Department for Education and Employment/Qualifications and Curriculum
48
49 Authority. (1999). *The National Curriculum for England: the programmes of study for*
50
51 *science Key Stages 1-4*. London, HMSO.
52

53
54 Driver, R. (1989). Students' conceptions and the learning of science. *International*
55
56 *Journal of Science Education*, 11, 481-490.
57
58
59
60

1
2
3 Driver, R., Guesne, E. & Tiberghien, A. (1985). *Children's Ideas in Science*.
4
5 Milton Keynes, Open University Press.
6

7
8 Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994). *Making*
9
10 *Sense of Secondary Science: research into children's ideas*. London, Routledge.
11

12
13 Gardner, H. (1999). *Intelligence Reframed: Multiple Intelligences for the 21st*
14
15 *Century*. New York, Basic Books.
16

17
18
19
20 Hellden, G. (1996) Elements in pupils' ideas about ecological processes. In A.
21
22 Giordan and Y. Girault (eds.) *The New Learning Models: their consequences for the*
23
24 *teaching of biology, health and environment*. Nice: Z'editions, 142-154.
25

26
27 Kinchin, I. M. (2000a). Concept mapping in biology. *Journal of Biological*
28
29 *Education*, 34, 2, 61-68.
30

31
32 Kinchin, I. M. (2000b). Using Concept maps to reveal understanding: a two-tier
33
34 analysis. *School Science Review*, 81, 41-46.
35

36
37 Kinchin, I.M., Hay, D. B. & Adams, A. (2000). How a qualitative approach to
38
39 concept map analysis can be used to aid learning by illustrating patterns of conceptual
40
41 development. *Educational Research*, 42, 1, 43-57.
42

43
44 Klein, D. C. D., Chung, G. K. W. K., Osmundson, E., Herl, H. E. & O'Neil, H. F.
45
46 (2001). *Examining the validity of knowledge mapping as a measure of elementary*
47
48 *students' scientific understanding*. Los Angeles, National Center for Research.
49

50
51 Lock, R. & Miles, C. (1993). Biotechnology and genetic engineering: students'
52
53 knowledge and attitudes. *Journal of Biological Education*, 27, 4, 101-106.
54
55
56
57
58
59
60

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

McClure, J. R., Sonak, B., & Suen, H. K. (1999). Concept mapping assessment of classroom learning: reliability, validity and logistical practicality. *Journal of Research in Science Teaching*, 36, 475-492.

Millar, R. & Osborne, J (1998). *Beyond 2000: science education for the future*. London, King's College.

Mintzes, J. J., Wandersee, J. H. & Novak, J. D. (2000) Assessing science understanding: A human constructivist view. San Diego, Academic Press.

Newton, P., Driver, R., & Osborne, J. (1999). The place of argumentation in the pedagogy of school science. *International Journal of Science Education*, 21, 5, 553-576.

Novak, J. D. & Gowin, D. B. (1984). *Learning How to Learn*. New York, Cambridge University Press.

Novak, J. D. & Cañas, A. J. (2007). Theoretical origins of concept maps, how to construct them and uses in education. *Reflecting Education*, 3, 1, 29-42.

Osborne, J., Wadsworth, P. & Black, P. (1992). *Processes of Life: Primary Space Project*. Liverpool, Liverpool University Press.

Osborne, R. & Freyberg, P. (Eds.) (1985) *Learning Science: the implication of children's science*. Auckland: Heinemann.

Reiss, M. J. (2002). Reforming school science education in the light of pupil views and the boundaries of science. *School Science Review*, 84, 307, 71-77.

Scott, P. (1987). *A Constructivist View of Learning and Teaching in Science*. Leeds, Centre for Studies in Science and Mathematics Education, University of Leeds.

Selley, N. (1999). *The Art of Constructivist Teaching in the Primary School*. London, David Fulton Publishers.

1
2
3 Shepardson, D. P. (2002). Bugs, butterflies, and spiders: children's understanding
4 about insects. *International Journal of Science Education*, 24, 6, 627-643.
5
6

7
8 Tobin, K. (1998). Sociocultural perspectives on teaching and learning of science.
9
10 In Larochelle, M., Bednarz, N. & Garrison, J. (Eds.) *Constructivism and Education*
11 (pp.196-212). Cambridge, Cambridge University Press.
12
13

14
15 van Zele, E., Lenaerts, J. & Wieme, W. (2004). Improving the usefulness of
16 concept maps as a research tool for science education. *International Journal of Science*
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Education, 26, 9, 1043-1064.

White, R. T. & Gunstone, R. F. (1992) *Probing Understanding*. London, Falmer
Press.

Yin, Y., Vanides, J., Ruiz-Primo, M. A., Ayala, C. C. & Shavelson, R. J. (2005).
Comparison of two concept-mapping techniques: Implications for scoring, interpretation
and use. *Journal of Research in Science Teaching*, 42, 2, 166-184.



A COMPOST HEAP



SICK CHILD



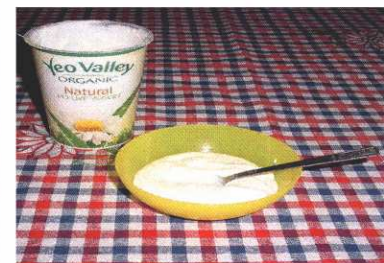
VACCINATION



BEER



MOULDY BREAD



YOGURT



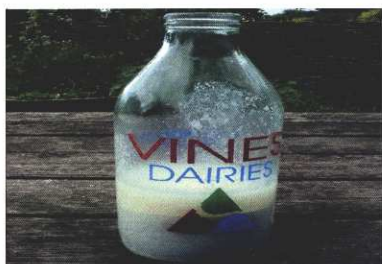
BLEACH



A SEWAGE WORKS



ANTIBIOTICS



SOUR MILK



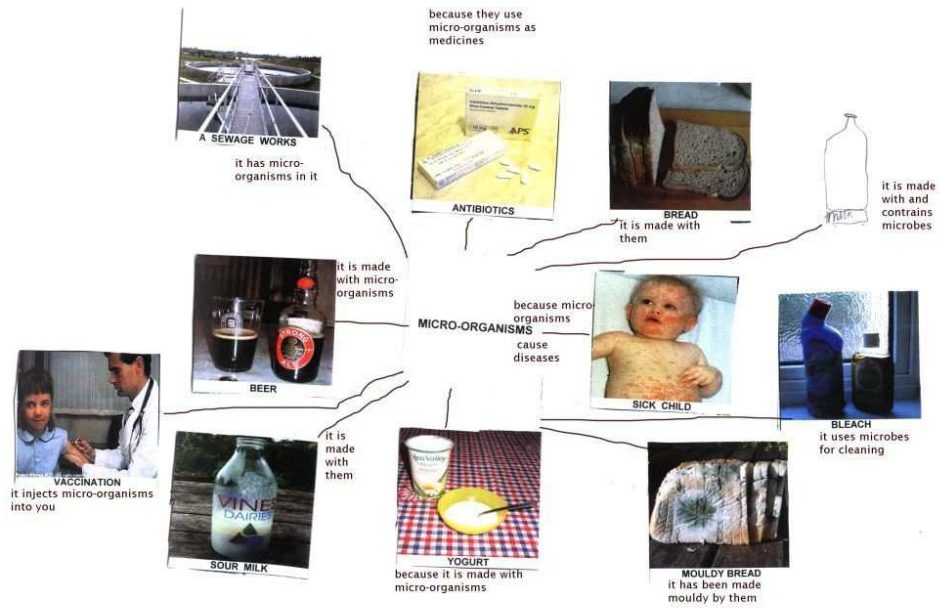
BREAD

MICRO-ORGANISMS

GERMS

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

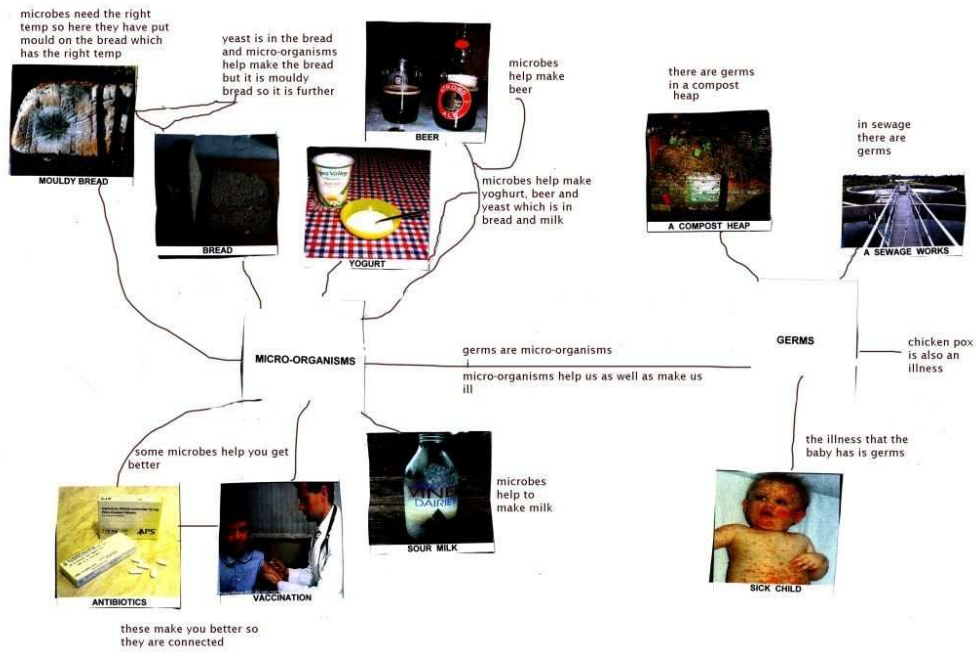
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



86x56mm (300 x 300 DPI)

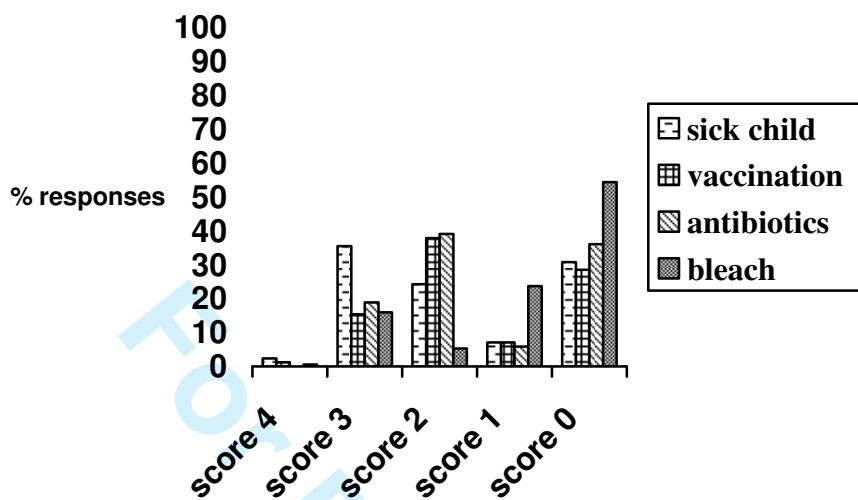
Review Only

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

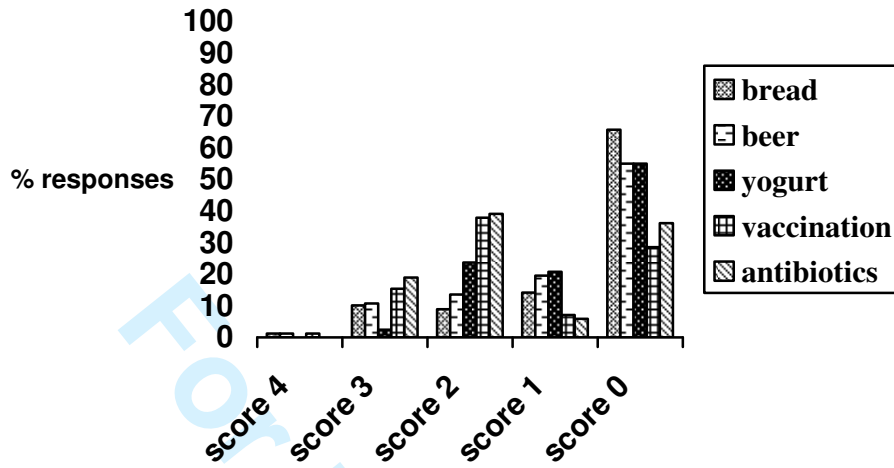


270x191mm (96 x 96 DPI)

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

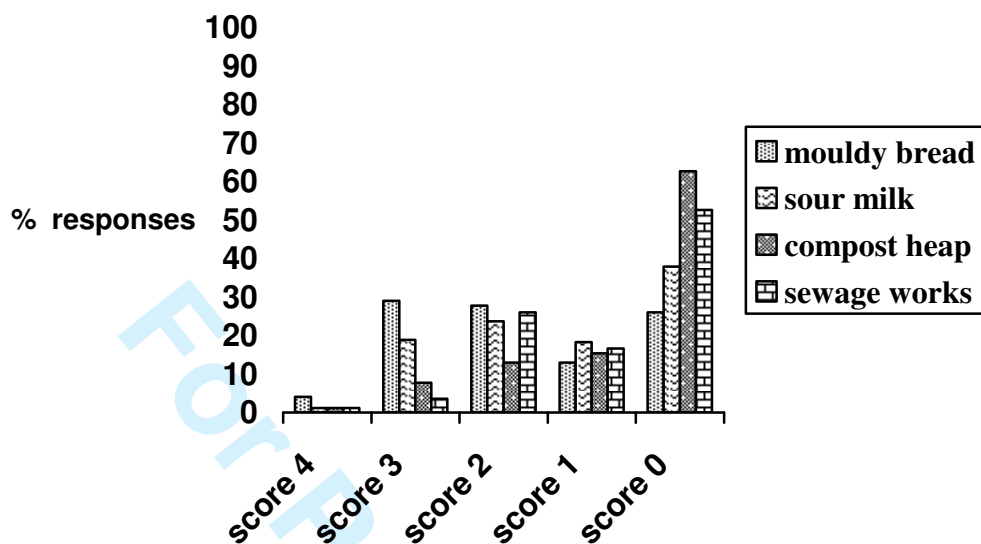


(score 4 = advanced statements, score 3 = more detailed / accurate statements, score 2 = appropriate statements, score 1= alternative/ non scientific statement- see Table 2)



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

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60



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

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

For Peer Review Only

Photograph	Scoring criteria
Sick child	1 = non scientific 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 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 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 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 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 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 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 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 statement 2 = micro-organisms present 3 = microbial causation 4 = microbial growth / fermentation of milk / culture produced
Compost heap	1 = non scientific 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 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

Photograph	Total Score	%	Total Score	%	Total Score	%	Total Score	%	Total Score	%
	=4		=3		=2		=1		=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	38.5
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

Table 4: Linking propositions between photographs

Linking propositions	Frequency
Antibiotics and sick child (medication)	19
Vaccine and sick child (medication)	19
Beer, yogurt and bread (food production)	12
Antibiotics/ vaccine/Bleach(antimicrobial agents)	11
Mouldy bread/ sour milk and child (cause illness)	9
Mouldy bread and fresh bread (decay)	7
Sour milk and mouldy bread (decay)	5