

# Children's anthropomorphic and anthropocentric ideas about micro-organisms

Jenny Byrne, Marcus Grace and Pam Hanley

University of Southampton, UK

*Different views exist about whether anthropomorphic ideas assist or hinder learning in biology. This paper discusses the anthropomorphic and anthropocentric ideas children have about micro-organisms, and whether they affect their understanding. The research was carried out in primary and secondary schools in the South of England and involved 414 children aged 7, 11 and 14 years. Three different research techniques were used to elicit their ideas. Anthropomorphic and anthropocentric ideas about micro-organisms are apparent in responses from all age groups. Anthropomorphic ideas seem to help children to explain their understanding of some aspects of micro-organisms but the imbalance in children's anthropocentric views of micro-organisms appears to prohibit them considering other aspects of micro-organisms; for example, the importance of their role in decomposition and cycling of matter, or their beneficial technological applications. The focus on the danger micro-organisms are thought to pose to human health creates a hostile view of micro-organisms and this may inhibit future learning.*

*Key words:* Micro-organisms, anthropomorphism, anthropocentrism, constructivism, learning

## Background

Anthropomorphism attributes human characteristics, both physical and mental – for example emotion, motivation and reasoning – to other living things and inanimate objects (Kallery and Psillos, 2004). Anthropocentrism on the other hand considers that human beings are the central and most important feature of the universe, and that any experience or understanding is interpreted exclusively from a human perspective.

Anthropomorphic ideas are commonly used by teachers and pupils to express their ideas about biological phenomena (Deadman and Kelly, 1978; Kattmann, 2008; Kallery and Psillos, 2004; Jungwirth, 1979; Tamir *et al*, 1981). However, the benefit to learning from using anthropomorphic ideas to explain concepts is disputed. Some consider that encouraging the use of anthropomorphic ideas is problematic as continued use may embed misconceptions (Jungwirth, 1975; Tamir and Zohar, 1991) and in some cases may lead to future emotional problems (Kallery and Psillos, 2004).

Opposing this view is a growing acceptance of the use of anthropomorphic ideas in learning and teaching. Treagust and Harrison (2000) advocate the use of anthropomorphism as a valuable pedagogical tool which provides explanations with which the students are familiar. Making use of anthropomorphisms in lessons may help to 'humanise' the science curriculum and make science more accessible to children (Watts and Bentley, 1994) by increasing their empathy with scientific topics (Zohar and

Ginossar, 1998). Indeed, making use of anthropomorphic ideas can promote learning (Kattmann, 2008; Tamir and Zohar, 1991; Zohar and Ginossar, 1998).

Furthermore, Engel Clough and Wood-Robinson (1985), Kattmann, (2008) and Zohar and Ginossar, (1998) argue that anthropomorphisms are such an integral part of human life and experiences that they cannot and should not be avoided. These ideas are mainly formulated in early childhood and younger children intuitively use anthropomorphic ways of explaining their ideas (Inagaki and Hatano, 1987), and they may be retained into adulthood by some (Brumby, 1982). However, these ideas are thought to reduce with age as children gain a more mature biological theory; and by about age 10 children can make the distinction between anthropomorphic and scientifically accurate ideas (Carey, 1985; Friedler *et al*, 1993).

Constructivist epistemology endorses the view that eliciting what children already know and understand about scientific concepts is important, because prior knowledge affects future learning. Previous ideas should not be ignored if good learning outcomes are to be achieved (Scott, 1987; Selley, 1999) because they can form the basis of conceptual restructuring (Ausubel, 1968) so that meaningful learning can then take place. From this perspective, children's anthropomorphic and anthropocentric ideas form part of their conceptual framework and need to be acknowledged to ensure effective learning.

The decision to focus on micro-organisms stems from

their undeniable importance to life on Earth. A thorough understanding of micro-organisms is essential if children are to grasp their vital importance in biological systems and increasing use in new technologies. However, there is currently a relative paucity of opportunities in science curricula in England for learning about micro-organisms. The research set out to discover:

1. What anthropomorphic and anthropocentric ideas do children have about micro-organisms?
2. Do anthropomorphic and anthropocentric ideas about micro-organisms alter with age?
3. Do children use anthropomorphic and anthropocentric ideas in their explanations of micro-organisms and microbial activity?

## Methods and participants

This is an interpretive study of children's anthropomorphic and anthropocentric ideas about micro-organisms (Cohen *et al*, 2007; Denzin and Lincoln, 2000) in which a constructivist approach is adopted where children's ideas about scientific phenomena may be developed from everyday experiences and do not necessarily adhere to accepted scientific warrants and claims (Driver *et al*, 1994). A total of 414 children, 159 aged 7 years, 166 aged 11 years, and 89 aged 14 years were involved in the study. The sample was drawn from primary and secondary schools in the South of England with catchments that were broadly representative of the school population in terms of academic ability, socio-economic factors, gender and ethnicity.

Three distinct research techniques were employed to elicit children's ideas. The 'draw and write technique' (Williams, Wetton and Moon, 1989) was used to ask children to draw and annotate their drawing of a micro-

organism. They were asked to write down all they knew about micro-organisms in a brainstorming activity. Finally, a sample from each age group was followed up with semi-structured one-to-one interviews to obtain more in-depth data (Denscombe, 1998). This sample was selected by examining the drawings and brainstorms that contained the most accurate or unusual information in order to represent the full range of ideas.

Anthropomorphic and anthropocentric ideas were identified in the data from all the techniques employed across a range of conceptual themes. These were:

- appearance
- size
- the living state
- location
- disease
- decay and cycling of matter
- microbial applications

## Findings

The anthropomorphic and anthropocentric ideas children have about micro-organisms, whether these change with age, whether they enable children to explain their ideas and whether they affect an understanding of microbiology are presented within each of the conceptual themes. Table 1 provides a summary of the anthropomorphic and anthropocentric ideas found in all age groups.

Both anthropomorphic and anthropocentric ideas reduced with age, although evidence suggests that anthropocentric ideas are more resistant to change. Anthropomorphic ideas, including attributing human qualities like well- or evil-intentioned and exemplified in the usage of terms such as 'good' or 'bad', seem to

**Table 1. Summary of children's ideas about micro-organisms**

<i>Conceptual area</i>	<i>Anthropomorphic ideas</i>	<i>Anthropocentric ideas</i>
Appearance	Attribute human physical characteristics to explain ideas e.g. modes of infection	Cause harm to humans, unpleasant and offensive, associated with harmful activities
Size		Virulence equates to size
The living state	Give a persona and physical human characteristics to explain ideas e.g. movement, reproduction, sensitivity	Speed of reproduction and large numbers become a danger Cause human illness
Location	Imbue with free will	Found near/on human beings to cause harm Dirty and unhygienic conditions – pose danger to humans
Disease	Have physical characteristics to facilitate infection	Cause harm/diseases that can result in death
Decay and cycling of matter	Eat the decaying item	Unhelpful for humans but useful for microbial reproduction – hazardous to humans Improves the environment, removes items that may be dangerous to humans Can improve soil to grow things
Microbial applications	'Good' micro-organisms used	Cause contamination of food and make humans ill Focus on antimicrobial properties of medicines

provide children with a means of explaining their ideas. Their use may offer teachers, through exploration of these initial ideas, opportunities to develop and deepen children's scientific understanding of micro-organisms. Anthropocentric ideas focus on micro-organisms in relation to the effect they are thought to have on humans, leading to a predominantly negative perspective which may not allow development of scientific thought.

**Appearance**

Anthropomorphic representations of the external appearance of micro-organisms were drawn by 49% (78/159) of 7 year-olds, 18% (30/166) of 11 year-olds and 18% (16/89) of 14 year-olds (Figure 1). Humanised representations (for example, facial features) were represented in

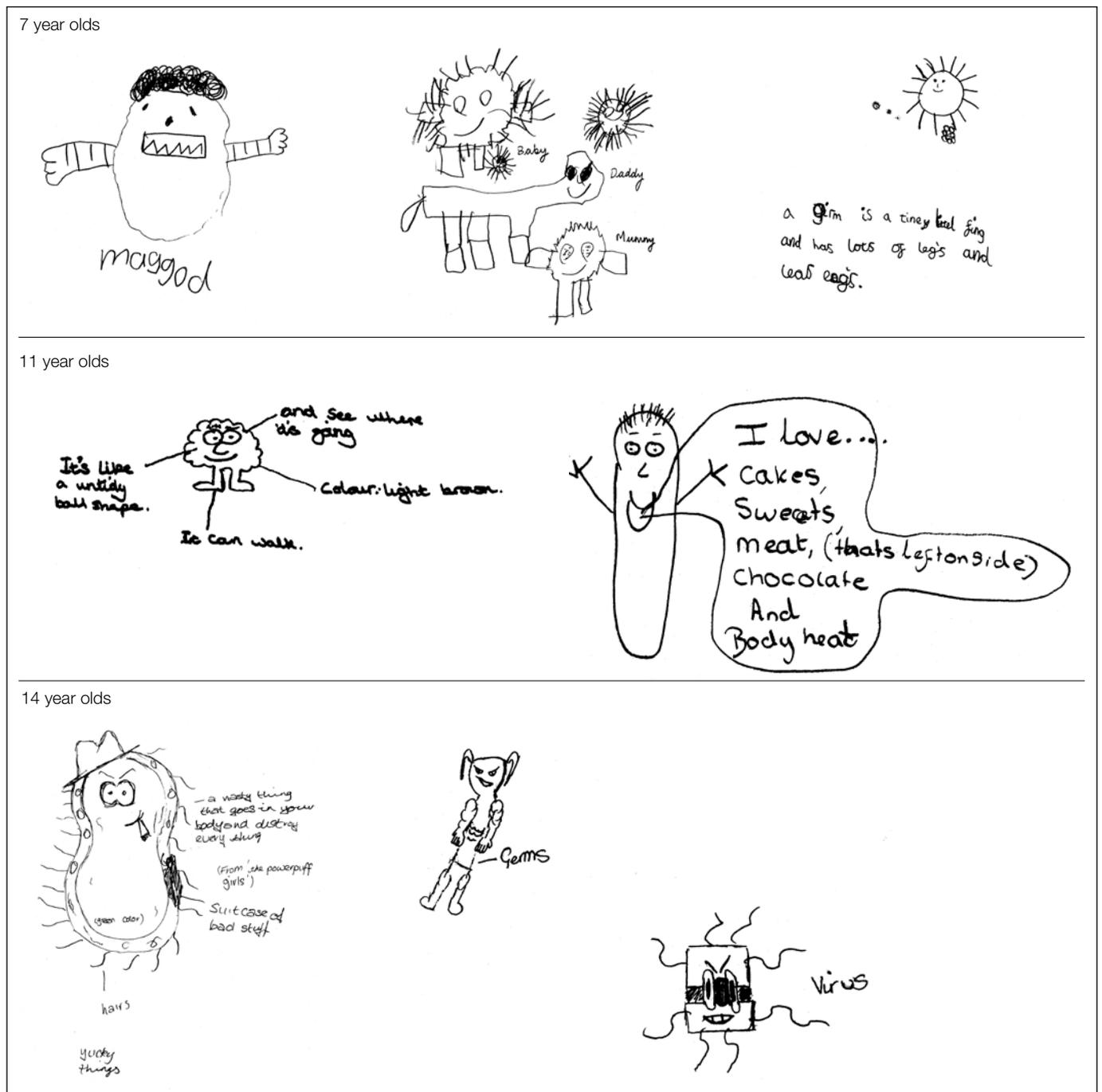
all age groups. Seven year-olds regard their representations as literally true, but these ideas seem to help them make sense of abstract concepts; in this case modes of infection:

Anna (7) *Well, these bits here, they are sort of like things that help them get inside the body so it all goes sssbbb! And it helps them get inside... That helps them to sort of like move and stuff, like legs we have except they have three... sort of like all sticky on the bottom.*

Interviewer *Why would they be sticky?*

Anna (7) *To help them cling on to the place, and to help them so they don't fall off. They're trying to get onto the side of the body.*

Figure 1. Examples of anthropomorphic drawings



Interviews showed that 11 and 14 year-olds had a greater awareness that their drawings were metaphorical representations rather than reality, but they continued to use anthropomorphic language to help them interpret their ideas and explain particular concepts, as shown in this exploration of beneficial and non-beneficial bacteria:

Interviewer *Why did you draw them like that?*

Jane (11) *Um well, just because I think they're like that.*

Interviewer *That's what they look like?*

Jane(11) *No, just because that one is sort of smiling because it's good and the other one is bad, but they don't look like that.*

Some 40-50% (40/78 7-year olds, 12/30 11-year olds, 9/16 14-year olds) of the anthropomorphised representations were represented negatively, or in association with unpleasant or dangerous activities in each age group (Figures 1 and 2) and frequently given a cartoon-like appearance. Whilst older children seem to understand that these were representative of an idea they were attempting to portray – in this instance the infection process – nevertheless the negative connotations they have about micro-organisms were very evident:

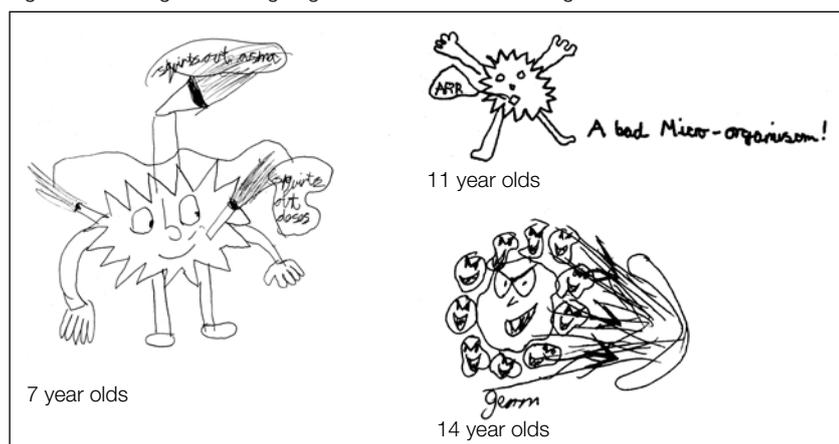
Mary (14) *Because it's a bad thing and it's evil, so I did evil eyes and horrible teeth and they're the white blood cells and the bacteria's going to eat the white blood cells.....to make the person ill.*

Interviewer *Do you think they look like this?*

Mary (14) *No, noooo.....they don't actually look like that.*

Negative attitudes and ideas towards micro-organisms were common across age all groups, *'it wouldn't have a smiley face because they're not friendly'* (Peter, 7), *'a little cold heart....because they're nasty'* (Gemma, 7) and indicate an aversion to micro-organisms, *'when I drew this picture I shivered as I drew more and more germs'* (Daren, 7), or suggest that micro-organisms are unpleasant and offensive or dangerous, *'each ring is a different shade of green with millions of purple dots floating around on it (yuk!)*' (Rosie, 11), *'acid on head to burn and penetrate'* (James, 14), *'a nasty thing that goes in your body and destroys everything, suitcase of bad stuff,*

Figure 1. Drawings illustrating negative views about micro-organisms



*yucky things'* (Fiona, 14).

### Size

All interviewees know that micro-organisms are very small. A small number (2/10 7-year-olds, 3/11 11-year-olds and 3/9 14 year-olds) used ontological ideas to reason anthropocentrically that virulence to humans equated to size, *'The ones that [are biggest] cause the most harm on your body'* (Gemma, 7), and in particular viral proliferation, *'I've seen like, virus because, I had rashes and, chicken pox is a virus and I've had that..... viruses are quite big because they can spread'* (Sophie, 11), *'viruses are [biggest] ..... viruses can easily spread.... With viruses, sort of like, you know, it's easy to catch it'* (John, 14).

### The living state

Drawings and annotations indicate anthropomorphic ideas about micro-organisms as living things are present in all age groups, *'he crawls with his back facing the ground, it has 18 legs'* (Greg, 7) whilst 11 and 14 year-olds also provided teleological reasons for their structures, *'it can walk and see where it's going'* (Will, 11), *'legs to move'* (Carol, 14). In some cases micro-organisms were attributed a persona and imbued with conscious thought (Figure 1). Table 2 shows the number of anthropomorphic and anthropocentric responses provided from brainstorming about the living state. Anthropocentric notions of micro-organisms causing harm, or illness, to humans as reasons for being alive predominated brainstorming and interview responses, *'cause if they weren't alive they wouldn't be able to move to kill people'* (Abi, 7), *'...if it can spread and go into your body and harm you in such a way then it must be living, and nothing dead could really harm you'* (Steven, 11), *'because they're all kind of, make you really ill'* (Mary, 14).

Reproduction was associated with the idea of proliferation often to other places or people, *'they can spread about onto other people'* (Simon, 7) and cause harm *'sucks blood, spreads lots'* (Mike, 7), *'it breeds at an amazing rate'* (Nick, 11). Notions of the speed of reproduction often seemed to be connected to ideas about the pervasive and dangerous nature of micro-organisms to humans:

John (14) *How fast it reproduces, how rapidly it, sort of, spreads that's important because, um, it gives you an idea of how bad it can be... lets say, germs for instance, they can spread everywhere... because you can get ill from germs and bacteria.*

### Location

Anthropomorphic ideas regarding micro-organisms as conscious beings occur in all age groups with respect to where they can be found. Reasoning seems to be based upon their desire to find a suitable place to live and this may help children in all age groups develop notions of the ubiquity of micro-organisms, *'it might be because it*

just... um, they just decide to be in something. They just think 'I want to go' (Grace, 7), 'everywhere really ... well the bacteria looks out for like animals and urine' (Steven, 11), 'just about everywhere ... they're trying to find somewhere to reproduce' (Roy, 14).

Table 3 shows the number of responses provided from brainstorms about microbial location; all age groups associate micro-organisms with humans and dirty or unhygienic conditions indicating a negative view, although this is more prevalent in 7 year-olds. These ideas are coupled with the danger they pose to human beings, 'I know they make you poorly, I know they live in dirty places because dirty places make you sick' (Dan, 7), 'they can make you ill, they are all over you' (Pat, 11), Sam (14)

*You can find them in bins and things like that, where loads of germs are. You can find them on people as well. 'Cause where there are germs a lot of people have got those, like colds and things like that. You find them there because that's where the germs are because, where they're bad things you find loads of germs, like rubbish and bins and things like that.*

**Disease**

The most cited microbial activity provided in the brainstorm responses (Table 4) from all age groups was as agents of human disease. During interviews, all seven year-olds, ten out of eleven 11 year-olds and eight out of nine 14 year-olds stated that the key idea they had about micro-organisms was that they were harmful to humans, 'they make you ill, well you can get sick and also get really really ill' (Alan, 7), 'they can like, make you really ill, you know, cause infections and stuff like that and it can kill you also' (Karen,11), 'they make you feel ill and horrible and they put disease in you' (Mary, 14). These anthropocentric ideas are reminiscent of 'microbe-mania': when the germ theory of disease became the predominant idea in nineteenth-century Europe and any illness was potentially linked to micro-organisms (Raichvarg, 1995).

**Decay and cycling of matter**

The role of micro-organisms in the decay process was not evident in data from drawings or brainstorms. Interviews revealed that all forms of decay were considered negatively and from an anthropocentric perspective by the majority of children. Reasoning was based upon the presence of micro-organisms that could harm humans:

Grace (7) *I think it might be a bad thing because, one day you might decide to move it (compost heap) somewhere else and you might pick it up and lots of germs might get inside you and harm you because they're all gathered together*

**Table 2. Brainstorm comments about the living state**

	7 year-olds n=23		11 year-olds n=79		14 year-olds n=42	
	no.	%	no.	%	no.	%
Anthropomorphic	3/23	13.1	18/79	22.8	0	0
Anthropocentric	15/23	65.2	30/79	38.0	6/47	12.8

Food spoilage was the only form of decay mentioned in the brainstorm activity by 11 and 14 year-olds; interviews revealed that decay was regarded primarily as a negative outcome of microbial activity, for example, this response to a compost heap, 'Bad. Because it just looks so bad...horrible', (Frank, 11) and because of microbial presence it could be dangerous, 'it could be bad because if you leave it for too long, bacteria might build up and grow really big and spread', (Fiona, 14).

Anthropomorphic notions of microbes 'eating' away the substrate, and multiplying were commonly used to help to explain the decay process, 'Yeah, because they like eat some of it and dispose of it' (Steven, 11) but knowledge is limited and tends to focus on the disappearance of the rotting item, 'They, feed on it and it turns into germs and goes', (Amy, 14). The role of micro-organisms in the cycling of matter is not understood, even when compost heaps were thought of positively; the outcome was to improve the soil, 'because it makes the soil, um, lots of nutrients in it?' (Liz, 14) and in doing so helps humans to grow plants, 'I think like compost when you rot all the stuff down and then you can use it as, nutrition, like mud and it helps your plants grow and stuff' (Charles, 11).

Micro-organisms are regarded as opportunists, in the decay process to multiply, 'It's turned into germs and so it's going everywhere ..... it's bad because then germs will grow on other things and go other places' (Amy, 14). Whilst this is regarded as a useful outcome for micro-organisms it is perceived as a threat to human beings because of increased numbers and consequently the greater danger this presents, 'good for the micro-organism but not for us' (Mary, 14).

Anthropocentric ideas are also evident – unhelpfully so – in children's reasoning about the beneficial outcomes of decay. Micro-organisms are seen as helpful in making the environment tidy for human beings, 'yeah, it's good, because if you, sort of bad everything in the world, and it wouldn't rot away, then it would be just a wasteland and everything would be piled up' (Jane, 11) or removing unwanted or potentially dangerous items, 'they rot dead

**Table 3. Brainstorm comments about location**

	7 year-olds n=51		11 year-olds n=71		14 year-olds n=17	
	no.	%	no.	%	no.	%
Humans	25/51	49.0	32/71	45.0	11/17	64.7
Dirty/unhygienic conditions	14/51	28.0	8/71	11.3	2/17	11.8
Animals	10/51	19.6	4/71	5.6	0	0
Everywhere	3/51	5.9	27/71	38.0	5/17	29.4

**Table 4. Brainstorm comments about microbial activity**

	7 year-olds n=139		11 year-olds n=147		14 year-olds n=78	
	no.	%	no.	%	no.	%
	Disease / illness	91/139	65.5	92/147	63.0	33/78
Food contamination/ spoilage/decay	0	0	30/147	20.4	3/79	3.9
Food production	0	0	31/147	21.1	6/78	7.7

animals, humans and plants so they don't get in the way' (Nina,11), 'they kill things we don't want' (Amy, 14).

Anthropomorphic ideas seem to help children explain the decay process at a simple level, but the emphasis on microbial reproduction and the danger they pose to humans as a result seems to preclude any other ideas, especially their role in the cycling of matter. Negative and anthropocentric ideas prevail in 7 year-olds' responses about decay and are retained by a similar proportion of 11 and 14 year-olds (Table 5). The focus on the danger posed by decaying items seems to prevent a substantial proportion of children from developing their understanding, and those that do have some notions of the beneficial aspects of decay perceive these from an anthropocentric perspective.

#### Microbial applications

The only beneficial application of microbial activity cited was the manufacture of food (Table 4). Interviews (Table 5) revealed that all 7 year-olds have a negative view of micro-organisms that precluded them from considering this application, 'um because, if germs actually made that food, when you have it, it will make you ill' (Bob, 7). Some responses from 11 and 14 year-olds revealed that micro-organisms are a cause of contamination, and as a result the food becomes a hazard to human health:

Mary (14) *Cheese, people touch it, if they don't wash their hands, they kind of like get all germs in the cheese. Sometimes they hand pack it, sometimes they do it by machine, but they still put the Cheese on the conveyor belt, with their hands. Yoghurt ..., they're travelling through the air, and when they like, put the lid on, they could all travel inside it. And like stay in the yoghurt until someone eats it... make someone ill if the person eats it.*

Others indicated that micro-organisms are used in food manufacture and endow them with human traits, regard-

**Table 5. Responses to microbial activity from interviews**

Activity	Anthropocentric ideas		
	7 year olds n=10	11 year olds n=11	14 year olds n=9
Disease	10/10	10/11	8/9
Decay	10/10	5/11	5/9
Food	10/10	6/11	5/9
Vaccination	3/10	10/11	6/9
Antibiotics	2/10	6/11	8/9

ing them anthropomorphically as 'good' micro-organisms. The processes are not especially well understood although the power of advertising is evident in responses, 'I think it's because it's a bio-yogurt, I think there'd be, um, good micro-organisms inside it to like, help your body get rid of the nasty bacteria' (Charles, 11).

Table 5 shows the number of interviewees who knew what vaccine and antibiotics were; all considered both to be antimicrobial agents, 'Uh, to stop illness..... I think they put something that is a barrier against the micro-organisms so that they can't get through' (Neil, 11), 'Yeab, it sort of kills all the microbes and stuff' (Lily, 14). This is not surprising given that this is the most likely context children will have been introduced to them. A few children in all age groups have anthropocentric ideas of how vaccine produces acquired immunity but the role of micro-organisms in provoking the immune system is not acknowledged:

John (14) *It helps to fight, it's like a sort of medicine at the same time. It helps fight off any bacteria, and sort of diseases, or something like that. It's almost like as if it's giving your white cells some information, how to fight it off. Sort of like inside information, to fight it off.*

Only a few children knew that 'good' or 'helpful' micro-organisms are used in the production of vaccine or antibiotics. Anthropomorphic thinking seems to enable these children to begin to understand that not all micro-organisms are dangerous.

#### Discussion

Anthropomorphic ideas about micro-organisms are found in all age groups and include ideas about micro-organisms having both human physical and mental characteristics. These ideas reduce with age; 7 year-olds tend to have a highly anthropomorphic perspective which is in accordance with others' views about young children's naive biology (e.g. Carey, 1985) although anthropomorphic ideas are retained by a substantial minority of 11 and 14 years olds (Brumby, 1982). Children in all age groups appear to use anthropomorphisms to explain ideas about micro-organisms that are difficult for them to articulate in other ways. Responses from 11 and 14 year-olds indicate that even though some of their ideas are not completely scientifically accurate, for example notions of the infection process or decay, nevertheless anthropomorphic expressions used in a metaphorical manner provide a vehicle for their ideas. The older age groups appear to be aware that anthropomorphisms are 'ways' of explaining rather than a literal expression of reality. Anthropomorphisms seem to be a natural way of expressing ideas and as such appear to facilitate learning (Engel Clough and Wood-Robinson, 1985; Kattmann, 2008; and Zohar and Ginossar, 1998).

Unhelpful anthropocentric views about micro-organisms prevailed in all age groups. Micro-organisms are discussed predominantly in terms of the effect they have on humans. These ideas tend to indicate a negative view of

micro-organisms, specifically how harmful or dangerous they are to human beings, and that they are essentially malevolent. These responses reflect a fear of the effects of micro-organisms on human health and the need to avoid locations where they might be found. There appears to be a lack of knowledge of the application of micro-organisms in simple technologies or their role in decay and cycling of matter, and negative views are presented more frequently than positive aspects of micro-organisms, even though the 11 and 14 year-olds have had short teaching sequences about micro-organisms. Although anthropocentric ideas tend to reduce with age, some seem to be resistant to change. This may form a barrier to learning, indicated by the lack of development after 11 for a substantial number of children in many conceptual areas.

### Educational implications

The anthropocentric and negative ideas about micro-organisms that seem to be resistant to change warrant more frequent learning opportunities and a conscious deconstruction by teachers of misfounded anthropocentrism. On the other hand, anthropomorphisms explicitly employed as tools to explain ideas and act as vehicles for understanding may assist learning so that children can begin to develop more accurate biological knowledge and acquire scientific language to express their ideas.

Greater opportunities to teach and expand the breadth of study after 11, that build more coherently on previous learning, may improve levels of knowledge and understanding about micro-organisms so that progression does not plateau. Additionally, it may be helpful to begin teaching about micro-organisms earlier than is currently the case in England, in order to provide children with some formal learning experiences about the ideas they already hold and that could act as a platform for future learning. Making use of everyday experiences, for example, childhood vaccinations or illness will have helpful relevance for learners. Capitalising on these informal learning experiences and making positive use of them in formal learning situations may help children develop a more scientific notion of microbial activity and begin to temper some of the strongly negative emotional connotations that children appear to have.

Learning and teaching sequences should promote the beneficial aspects of micro-organisms that help children to develop a more realistic perspective of micro-organisms. These might include: increased opportunities for practical work, for example food technology beyond bread and yogurt production; making and investigating a compost heap; and visits to sewage works. Teaching should also further children's understanding of the significance of microbial activity in decay and cycling of matter by incorporating both the organic and inorganic aspects of these cycles when teaching about decay and decomposition.

### References

Ausubel D P (1968) *Educational Psychology: a cognitive view*. New York: Holt, Rinehart and Winston.

- Brumby M N (1982) Students' perceptions of the concept of life. *Science Education*, 66, 613-622.
- Carey S (1985) *Conceptual Development in Childhood*. Cambridge: MIT Press.
- Cohen L, Manion L and Morrison K (2007) *Research methods in education*. London: Routledge.
- Denscombe M (1998) *The good research guide for small-scale social research projects*. Buckingham: Open University Press.
- Driver R, Squires A, Rushworth P and Wood-Robinson V (1994) *Making sense of secondary science: research into children's ideas*. London: Routledge.
- Deadman J A and Kelly P J (1978) What do secondary school boys understand about evolution and heredity before they are taught the topics? *Journal of Biological Education*, 12, 7-15.
- Denzin N K and Lincoln Y S (2000) *The discipline and practice of qualitative research*. In Denzin N K and Lincoln Y S (Eds) (pp 1-28) *Handbook of qualitative research*. Thousand Oaks, California: Sage.
- Engel Clough E and Wood-Robinson C (1985) How secondary students interpret instances of biological adaptation. *Journal of Biological Education*, 19, 125-130.
- Friedler Y, Zohar A and Tamir P (1993) The effect of age and of learning on the ability to distinguish between anthropomorphic and teleological explanations. *International Journal of Science Education*, 15, 4, 439-443.
- Inagaki K and Hatano G (1987) Young children's spontaneous personification as analogy. *Child Development*, 58, 1013-1020.
- Jungwirth E (1975) Caveat mentor – Let the teacher beware! *Research in Science Education*, 5, 153-160.
- Jungwirth E (1979) Do students accept anthropomorphic and teleological explanations as scientific explanations? *Journal of College Science Teaching*, 8 (8), 152-155.
- Kallery M and Psillos D (2004) Anthropomorphisms and Animism in early year science; why teachers use them, how they conceptualise them and what are their views on their use. *Research in Science Education*, 34 (3), 291-311.
- Kattmann U (2008) Learning biology by means of anthropomorphic conceptions? In: M Hammann, M Reiss, C Boulter and S D Tunnicliffe (Eds) *Biology in Context: Learning and teaching for the twenty-first century* (pp 7-17) London: Institute of Education.
- Raichvarg D (1995) *Louis Pasteur – L'empire des microbes*. Decouvertes Gallimard.
- 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
- Tamir P, Gal-Choppin R and Nussinovitz R (1981) How do intermediate and junior high school students conceptualize living and non-living? *Journal of Research in Science Teaching*, 18, 241-248.
- Tamir P and Zohar A (1991) Anthropomorphism and teleology in reasoning about biological phenomena. *Science Education*, 16(1), 83-97.
- Treagust D F and Harrison A G (2000) In search of explanatory frameworks: An analysis of Richard Feynman's lecture 'Atoms in motion.' *International Journal of Science Education*, 22 (11), 1157-1170.
- Watts M and Bentley D (1994) *Communicating in School Science: groups, tasks and problem solving 5-16*. London: Falmer Press.
- Williams T, Wetton N and Moon A (1989) *A picture of health: What do you do that makes you healthy and keeps you healthy?* London: Health Education Authority.
- Zohar A and Ginossar S (1998) Lifting the taboo regarding teleology and anthropomorphism in biology education – heretical suggestions. *Science Education*, 82(6), 679-697.

*Jenny Byrne (corresponding author) is a lecturer in education. Email: J.Byrne@soton.ac.uk. Marcus Grace is a senior lecturer in education. Email: M.M. Grace@soton.ac.uk. Pam Hanley is a research assistant at the University of York. Email: pb572@york.ac.uk*