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Children's Misconceptions in Primary Science: A Survey of Teachers' Views.

Running Head: Children's Misconceptions in Science

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Abstract

Young children hold naive theories about the world around them but how do these mediate science learning in primary school? This paper considers the process of conceptual change and describes empirical studies into children's naive theories of physics concepts. The Representational Redescription model (Karmiloff-Smith, 1992) is invoked to explain how naive theories are a feature of conceptual change. Data are presented from a survey of 122 teachers of primary science in England. The teachers rated almost one third of the topics sampled from the primary curriculum as being of above average difficulty for the children, particularly abstract concepts like electricity and forces. In addition, the teachers identified 130 misconceptions (such as "Stones grow" or

"Taller people are older than shorter people") which children bring to the science class. These data provide a starting point for considering how children's naive theories may mediate their ability to learn and implications for science teaching are discussed.

Introduction

When children in the UK first experience formal science lessons, usually at the age of five, the topics taught are not unfamiliar to them. Since the introduction of a National Curriculum for England and Wales, primary school children are now required to study Experimental and Investigative Science which includes Life Processes and Living Things, Materials and their Properties and Physical Processes (headings taken from the Key Stage 1 Programme of Study). Therefore, primary science lessons are likely to be based around the effects of physical forces like pushing and pulling, how plants and humans grow, or how various objects sink, float or balance. All of these are concepts which the children will have previously experienced in some form in their daily lives. And these experiences will have left their trace, since from them the children will have constructed a number of intuitive ideas and theories about how the world around them works (Kuhn, 1989).

'One of the most important findings of cognitive/developmental research is that children do not come to the science learning task as a 'tabula rasa' but they have acquired rich knowledge about the physical world based on their everyday experiences'.
(Vosniadou and Ionnides, 1998).

Conceptual change in science

The role for the primary teacher is to organise the child's naive ideas into a coherent concept which is both accurate and explicit. However, whether this involves discarding and replacing the initial knowledge, or reorganising and developing it, is a question that gives rise to two opposing views about how conceptual development in science occurs. Many existing characterisations of the process of conceptual change focus on a conflict between two sets of knowledge, where the child's incorrect one is finally abandoned in favour of the teacher's more correct conceptualisation (Posner, Strike, Hewson and Hewson, 1982). Carey espoused this view, by postulating that many of children's initial ideas about physics are incompatible with the adult concept, thus demanding a major reconceptualisation analogous to a paradigm shift in scientific theory (Carey and Gelman, 1991). Piaget, too, claimed that cognitive conflict would create disequilibrium and that, with maturation, misconcepts would fall by the wayside (Piaget, 1977).

On the other hand, there exists a significant and respectable body of literature that regards science learning as a gradual process involving the child's pre-existing knowledge of everyday physical phenomena gradually being enriched and restructured (Kuhn, Amsel and O'Loughlin, 1988; Clement, Brown and Zietsman, 1989; Vosniadou and Ionnides, 1998; Karmiloff-Smith, 1992). Clement et al. proposed that the child's intuitive ideas about science are 'anchoring conceptions' (1989, p.554) upon which new knowledge is built, Rosser describes them as 'the rudimentary kernels of more sophisticated knowledge' (1994, p. 170) and to Karmiloff-Smith (1992) they are the starting point for development. This restructuring position is also adopted by Spelke (1991) who argues that initial knowledge elaborates with experience but that fundamental principles are neither abandoned nor replaced. If new knowledge is built out of old, these fundamental principles ('anchoring conceptions', 'rudimentary kernels' or 'intuitive ideas') about science which children bring with them to the classroom must clearly play an important role in the process of learning.

This paper sets out to show that pre-existing knowledge, in the form of naive theories, are a pervasive feature of children's early understanding of science. It begins by providing empirical evidence from studies demonstrating naive theories within two scientific concepts, balance and curvilinear motion. A theoretical model to account for the restructuring view of conceptual change and the robust nature of some naive theories, Karmiloff-Smith's Representational Redescription Model, is then outlined. Having accounted, empirically and theoretically, for children's naive theories the paper presents data from teachers regarding children's naive beliefs about Key Stage 1 Science curriculum topics. Finally the implications these may have for science teaching are discussed.

Naive theories about balance

Balance is an activity which children engage in spontaneously during play and exploration. Building blocks encourage the child to place one object on top of another and the child learns spontaneously, through their play, that a small object cannot support a very large one unless the weight distribution is correct. Although children do not know any scientific explanations of balance, by 4 or 5 years they demonstrate considerable mastery of their spatial world and can build a tower with irregular sized blocks. Yet when a child of six or seven years is given a wooden beam - about 30cms long with a block of wood fixed to one end - and asked to let it rest upon a support so that it balances, they are often unable to do so (Karmiloff-Smith and Inhelder, 1974). In fact, in a study of 168 children aged four to nine we found that 80 of them could not balance a beam of this type upon a simple fulcrum (Pine and Messer, 1999). These children made the error of trying to place the mid-point of the beam onto the fulcrum, rather than placing it off-centre to compensate for it having more weight at one end. These findings have been replicated in a number of studies involving over 600 children (Pine, 1997).

The fact that many six and seven year old children fail at this task is important for two reasons. First because the task is not a difficult one and children as young as four or five can often succeed at balancing an unevenly weighted beam. Second, it is surprising because the children appear to ignore any information they sense via proprioceptive feedback from the beam they are trying to balance. The many children who consistently place an unevenly weighted beam onto the support close to its mid-point and, when it falls, report that it 'is impossible to balance' or 'can't be balanced' appear to have spontaneously developed beliefs about how things balance. These children seemed to operate according to a maxim, or theory, that 'all things balance in the middle' which led them to place even the asymmetrical beams onto the fulcrum at their mid-point. In our study, of the 80 children who were unable to balance asymmetrical beams, almost half of them (36) actually told us that things had to balance in the middle although in the remainder the theory was non-verbal. A question arising from this is, if the child ignores information from his own senses (proprioceptive feedback) will he find it difficult to assimilate evidence that is counter to his centre theory from a teacher?

Naive theories about motion

There is also evidence that, in their understanding of motion, children develop naive theories based upon erroneous principles. Kaiser, McCloskey and Proffitt (1986) found this in a study investigating what children know about curvilinear motion. The task involved showing children a drawing of a tube curved like a spiral and asking them to imagine that a ball was travelling inside the tube from the centre outwards. The child had to indicate the path they thought the ball would follow as it left the tube.

Only 25% of school children (mean age seven years 11 months) correctly predicted that the ball's path would be a straight line. The remaining 75% predicted, incorrectly, that it would continue on a curved trajectory. Younger children (pre-school and kindergarten) did not make this error and most predicted correctly that the ball would travel in a straight line. Just like the balance task, where younger children could balance all beams but most 6-seven years olds made the 'centre' error, kindergarten children were better at the curvilinear motion task than school children. Kaiser et al. conclude that younger children do better simply because they do not have any overarching theory of motion. Clearly it is having a theory that can lead to errors.

The persistence of naive theories.

These two examples highlight how children can have naive misconceptions about two basic scientific concepts, balance and motion. Pre-school children were better at doing both tasks than school-age children and Kaiser et al. concluded that younger children were more successful because they were working without any preconceived theory, whereas the older children in both studies had a firm theory about balance and motion. The term theory is used to describe these ideas because they embody knowledge which goes beyond mere empirical observation and serve as explanatory systems. Such theories may be verbalisable, as in the examples of children who told us that things balance in the middle, or they may be non-verbal and simply drive the children's judgments and behaviours without being articulated. The next section deals with the persistence of non-verbal and verbal naive theories and introduces a theoretical framework to take account of the cognitive processes underlying this phenomenon.

The Representational Redescription Model

Proposed by Karmiloff-Smith (1992), the Representational Redescription (RR) model claims children's initial knowledge about the world simply serves to enable them to interact successfully with objects. They can do this without any 'theories', explanations or taught knowledge, thus achieving considerable mastery by operating at this most basic or implicit level. In the examples described above the younger children succeeded at the balance beam and curvilinear motion tasks without knowing any of the 'science' about balance or motion. As they get older, children go on to spontaneously develop theories about their world. Karmiloff-Smith (1992) claims they are cognitively driven not just to act but also to understand and explain the world around them. Thus, their implicit knowledge forms the starting point for development which involves restructuring it into a more explicit format, termed Level E1 in the RR model. It is at Level E1 that the child creates some abstract knowledge about the topic, and the first stages of theory building begin. The first theory is one which best accounts for the experiences the child has encountered, like a heuristic, although the child may not be able to verbalise it. It initially is also somewhat oversimplified as we have seen in the examples of naive Level E1 theories in the studies quoted above. These theories took the form of a maxim that 'all things balance in the middle' as we saw with the balance beam studies. Or that 'moving objects continue to travel in the direction in which they are set in motion', in the studies into curvilinear motion. It is likely that there are also similar naive theories relating to science concepts taught in the primary classroom, which to date have not been clearly identified but which our work aims to elucidate. One cannot discount the possibility also, that teachers as well as children, may have misconceptions about primary science topics.

One explanation of the children's errors in the balance and motion studies described above could simply be that children find these concepts particularly difficult to grasp. One factor mitigating against this view, is the superior performance of the younger children. Additionally, the similarity and persistence of many children's errors suggest that the problems may reflect some general learning principles (and, therefore, that they might be found in other science topics). Also, observations regarding consistency among older students' misconceptions in science pervade the education literature. These include, to give a few examples, the common belief that heavier objects fall faster than lighter objects (Champagne and Klopfer, 1984), that gravity forces falling objects to always follow a straight trajectory (Hood, 1995), or that static objects cannot exert forces (Clement et al., 1989). Strongly held naive theories about number have also been said to account for children's difficulties when learning about fractions (Gelman, 1994) and decimals (Wearne and Hiebert, 1989), suggesting that although this phenomenon is found in the science domain, it also extends to other areas of learning. Karmiloff-Smith (1992) also applies the RR model to the domains of language learning, mathematics, drawing and social understanding and seems to offer the most plausible model for explaining the cognitive processes underlying the development of naive theories.

Why should children develop their own naive ideas about the world, if so often these are incorrect or incomplete? Prior to being exposed to any formal science education these naive ideas served to give the very young child some basic principles and heuristics for dealing with the world around him since most of the time they are proved right. The fact that they are inaccurate, erroneous or incomplete also means that, whilst they may have been useful in an informal setting, they can actually hinder the child's ability to learn further about a topic in the context of more formal education (Driver, 1981; Driver and Erickson, 1983; Karmiloff-Smith, 1992; Klaczynski and Narasimham, 1998; Kuhn, 1989; Schauble, 1996).

Many writers have attested to the robustness of false or partial beliefs, and to how they impede new learning, "Not only are students' explanations incorrect, but their faulty explanations are extremely resistant to change" (Ferrarri and Chi, 1998, p.1234). And conducting science experiments in a formal setting, like the classroom, does not necessarily cause students to alter their misconceptions. Schauble (1996) found that despite having six half-hour sessions to explore the causal structure of 2 physical science domains (density and hydrostatics), many children and adults still retained their incorrect beliefs. Schauble noticed that the participants refused to generate evidence or entertain ideas that did not fit with their existing knowledge, causing them to dismiss relevant evidence and cling rigidly to their current beliefs even when they were wrong. In our studies with children and the balance beam task, we have also found that children fail to relinquish their 'centre theory' after seeing an adult modelling the correct solution, or collaborating with others (Pine and Messer, 1998; Pine and Messer, in press). According to Rosser (1994), existing beliefs act as a set of biases which interfere with subsequent knowledge acquisition by affecting which sets of evidence are deemed to be relevant. This can have serious implications in the classroom, where the view of the child as a rational empiricist still predominates. A teacher may use the demonstration-observe-explain technique to get a new concept across to children (e.g. Champagne, Gunstone and Klopper, 1985), but the teacher knows from the outset how an experiment should be interpreted and the children do not. The children tend to make 'theory laden observations' (Driver, 1990) and may only observe aspects of the demonstration which support their own theory. Klaczynski and Narasimham (1998) say this happens because belief-enhancing evidence is processed with less cognitive effort than incongruent evidence, explaining why the latter is less readily assimilated into existing knowledge structures (Kuhn, 1989).These factors may, therefore, affect the teachability of children when science concepts are presented in the classroom. Evidence is emerging that calling to mind the child's false belief prior to instruction may be an effective teaching method (Pine and Messer, in prep; Kloos and Somerville, 1999). Therefore it will be important for educationalists to be aware of the types of naive theories children hold.

There currently appears to be scant empirical evidence concerning whether children construct these Level E1 or naive theories about the science topics which they encounter in their primary science class, although the teachers we spoke to informally suggested this was extremely likely. We were also given the impression that teachers do not go out of their way to find out about children's wrong ideas, but place emphasis on correct knowledge, although as we discuss later the incorrect ideas may be the foundations upon which new knowledge is built and should be acknowledged. In this paper we put some of the key concepts of the National Curriculum Key Stage 1 Science programme under the spotlight in order to identify which topics children already hold a naive theory about and what form the theory might take. The importance of having this knowledge is that it can provide invaluable information for the teacher about the pre-existing knowledge which the children come to science lessons with, the receptivity of children to the new concept and the best approach to teaching.

Method

After informal consultation with a number of primary school teachers a questionnaire was developed (see Appendix A) aimed at identifying children's naive theories about topics within the Key Stage 1 curriculum. Piloting of the questionnaire resulted in the reordering of items to place the science statements at the beginning of the questionnaire.

Participants

Copies of the questionnaire were sent to primary schools in four education authorities selected at random from those in England. Two hundred schools in total received questionnaires accompanied by a letter to the head teacher asking for the school's cooperation and requesting that it be filled in by a teacher (or by teachers) who had been teaching Key Stage 1 Science (i.e. to children in Years 1 and 2, ranging from five to seven years of age) for at least a year. Of the 200 schools approached, eighty one schools (40%) replied, with questionnaires from a total of 122 teachers. The mean length of the teachers' teaching experiences was 14.91 years. The average size of the schools who responded was 267 (as indicated by number on school roll, ranging from 70 to 550) with, on average, 10.01% of their pupils having English as a second language. Four teachers did not indicate their subject specialism but 34 of the teachers who responded said they were science specialists, 84 said they were teaching Key Stage 1 Science but that science was not their specialism.

Results

The questions posed to the teachers produced three sets of information for analysis using both quantitative and qualitative methods. The first set of questions concerned the science topics which children had difficulty with and the types of naive ideas exhibited by the children. These data are dealt with below, forming the first part of the results section. Following this, the teachers responses to questions regarding their own awareness of children's preexisting knowledge and how this affects learning, make up section 2. Lastly, data relating to children's understanding of scientific experimental procedures are presented in the final part of the results section.

1. Questions about 'difficult' science topics and the misconceptions which children have.

Question 1:

The first part of the questionnaire required teachers to rate 22 science statements according to the perceived level of difficulty for the child. The rating scale was 1 = Very easy , 2 = Easy, 3 = Average, 4 = Difficult, 5 = Very Difficult. This question was answered by all respondents, producing 122 ratings for each of the 22 statements. Fifteen of the statements received a mean rating of 3 or less, denoting average or less than average difficulty. Seven statements received a mean rating greater than 3, indicating that almost a third of the topics were rated as having above average difficulty (see table 1).

[Insert table 1 about here]

Question 2

Since the statements given in Question 1 only related to part of the Science curriculum, this question sought to discover whether there were other science topics teachers thought children found difficult. Question 2 therefore stated: "Please look again at the list of statements in Q1. Are there any that you would add to this list which would be 'difficult' or 'very difficult' for the child?". Table 2 shows the difficult concepts identified by 43 teachers who responded to this question.

[Insert table 2 about here]

Question 7

Having asked teachers which topics children find difficult, they were also also asked to give examples of common ideas held by children. This produced a total of 130 responses from 90 teachers (74% of the sample). The wrong ideas appeared to fall into three categories, although these were not always mutually exclusive and overlap did occur. They appeared to take the form of overgeneralised rules, misconceptions and linguistic or semantic errors. Overgeneralised rules describes ideas which are right some of the time (e.g. that larger objects weigh more than smaller objects) but are not scientifically accurate. They are therefore invalid when overgeneralised, partial as theories and limited in scope. Misconceptions, on the other hand, are never right (e.g. that the sun turns into the moon at night) and are completely at odds with scientific teaching. Linguistic and semantic errors arise from children's linguistic confusion or limitations (e.g. the idea that 'waves' refers to the beach and not sound or a fair test being one where 'everyone gets a turn').

The data which follow describe the false beliefs identified by teachers under each of the headings in the National Curriculum Programme of Study: Life Processes and Living Things, Materials and their Properties and Physical Processes.

1. Life Processes and Living Things

In this part of the curriculum children are required to learn about life processes and living things under five headings: Life processes, humans as organisms, green plants as organisms, variation and classification and the environment of living things. In Question 1 five statements were posed relating to this part of the curriculum (Statement nos. 14, 15, 16, 17 and 22) and these five had a mean difficulty rating of 2.36 suggesting that these topics were of average difficulty or fairly easy for children to understand. Of the 130 responses relating to misconceptions in Question 7, 39 arose from this part of the curriculum (33%).

Living/Non-Living Classification: Teachers told us that a common idea amongst children is that plants or trees cannot be living things. This arose from children believing that living things move and non-living things do not. Another belief identified is that 'everything in the ground grows', giving rise to the notion that even 'stones grow'. Just what qualifies as an animal posed problems for children. Teachers reported the idea, held by Year 2 children (six to seven years), that all animals were furry, four legged creatures and that neither humans nor insects could be classified as animals. Another teacher confirmed this, saying that children have a limited idea of what an animal is, often restricting it to farm and zoo animals.

Plant Growth: this accounted for a number of responses (14 instances), including the notion that plants die if they are not kept on a windowsill, or that the bigger the plant is the healthier it must be. Seeds were believed to come 'from a packet' rather than from an adult plant and thought to contain a baby plant inside them. One teacher also reported a child's belief that a pencil was a plant, another that plants will grow without light as long as they have water. Human Growth: Children were frequently reported to believe that height is dependent on age, so that taller people must be older than shorter people. Another belief is that all men are taller than women or that a person gets bigger on their birthday. Teachers also reported difficulty for children understanding where organs are inside the human body and having the belief that death is a reversible process.

Under the rubric of Life Processes and Living Things, in the sub-category 'Humans as organisms', children are required to learn that 'humans have senses which enable them to be aware of the world around them'. Misconceptions about vision were identified by teachers in their responses to question 7. Teachers reported the belief among children that we see from the eye outwards rather than because light gets into it. One teacher likened the child's concept to Superman and having X-Ray vision, the notion that a force comes out of the eye that makes one able to see, 'When studying the five senses, this crops up time after time' was the comment made.

2. Materials and their Properties

This part of the curriculum states that pupils should be taught to group materials (on the basis of a variety of properties) and to understand changing materials (as a result of processes such as squashing, bending, heating cooling etc.). In Question 1 some of these concepts were explored in Statements 10, 11, 12, 13 and 19. The mean rating for these five statements was 2.78. Only Statement 19, 'Steam can change back to water' achieved a rating greater than 3 (mean = 3.74) but, when probed for misconceptions, 11 responses from teachers identified erroneous beliefs surrounding the concepts of materials and their properties (8% of the total).

Materials: A teacher reported the belief that the world could be divided into things that are wood and things that are metal, another that all materials are made by man and none occur naturally. Another child believed that since rocks are dead they could not be natural. Children were reported to believe that the term 'material' was restricted to cloth and fabric, presumably because this is how they have previously heard the term used, and did not consider rocks and plastic to be materials. When learning about food, not all children appeared to understand that food stuffs occur naturally, since there were two instances of children believing that flour and apples come "from the shops"!

Changing materials: Five teachers mentioned that children mix up steam with smoke or mist and do not realise where condensation comes from. Melting, dissolving and disintegrating are also confused, according to three respondents, with one teacher quoting the misconception that, "Squeezing an ice cube hard causes it to disappear". Another proposed the notion that melted materials can become solid again as being hard for children to understand.

3. Physical Processes

In this part of the science curriculum pupils are required to learn about electricity, forces and motion, and light and sound. There were twelve statements in Question 1 which explored this part of the curriculum. Their mean 'difficulty' rating of 3.1 suggested that this included the topics children had the most difficulty with. "Anything to do with forces is very difficult for KS1 children to understand" wrote one teacher, and this view was echoed by many others. As if to confirm this, in their responses to Question 7, 70 of the 130 misconceptions mentioned by teachers (54%) fell under the Physical Processes heading. Even the general meaning of a 'force' was reported to confuse some children, who only understood the term in the context of 'forcing' someone to do something.

Electricity: In relation to the understanding of electricity teachers reported that children thought a battery will always light a bulb. Electricity was also related to heat in the children's minds, making it hard for them to understand that a fridge uses electricity. One teacher reported that electricity is difficult for children because they cannot see it, others said, "There are difficulties with forces because the children cannot see the forces, only the effects" and "It can't be seen but it's there". It was also reported that children think 'electricity is an object which is 'boxed' in some way'.

Floating and sinking: These concepts were frequently quoted as giving rise to misunderstandings. Analysis of the questionnaires found 17 separate instances referring to wrong ideas about floating and sinking, based mostly on the maxims that 'large objects sink, small objects float' and that 'all heavy things sink and all light things float'.

Weight and size: These were believed to be correlated, i.e. something which is bigger will be heavier regardless of material or solidity ("even when shown conflicting evidence" was how one teacher referred to the robustness of this idea) in a similar way to how age and size in people is believed to correlate. This crossed to the concept of gravity too, with large objects believed to fall faster than small objects and objects, in general, believed to fall at different speeds.

Sources of light: One child thought you light a bulb by putting it in the sun, another believed that lights are the main source of light. Four teachers highlighted the misconception that the moon is a source of light, and there were eleven separate references to misunderstandings about the sun. These mainly concerned the belief that the earth stays still and the sun moves around it or even that the sun turns around at night and becomes the moon. Related to this is children's understanding of daylight, which revealed ideas about natural light coming from the sky in general, rather than from the sun (since it is still light on a cloudy day when the sun is not visible), and the notion that light is a 'normal' state of affairs and darkness is 'turned on and off'. The expression that at sunset the sun 'goes down in the sky' was given by one teacher as an example of how language can reinforce children's wrong ideas.

Shadows: Unsurprisingly, then, there were also some misconceptions about shadows, including the belief that a shadow would occur between the sun and the object, that shadows could occur separately from people or objects, failure by children to realise that their shadow moves with them and some general confusion about the difference between reflections and shadows.

Sound: In Question 1 we had explored children's understanding of sound in Statements 8 and 9, neither of these were judged as 'difficult' by teachers. However, one teacher pointed out that it is difficult for children to understand that sound is produced by vibrations, another reported children's confusion over high and low pitches and another difficulty with the fact that sound travels in waves. Similarly, light travelling in beams, rays or waves ('most children thought about the beach') appeared to give rise to confusion in children.

2. Questions relating to children's pre-existing knowledge, and the effect teachers think this knowledge has on learning ability.

Question 3: When you are teaching a new science concept, how important do you think it is to find out what children already know about the topic?
In general, teachers thought this was important. Their responses were on a scale from 1 = Very Important to 4 = Not important. The mean for the sample was 1.38 (sd = 0.66). This did not appear to be affected by how experienced the teachers were, since there was no significant correlation between teachers' responses and their years of teaching experience ($R2 = 0.0238$, ns).

Question 4: When teaching a new science topic, how often do you find you are fully informed about what children already know about the topic?
Again, teachers felt they had a good idea of what children already know. Their responses were on a scale from 1 = Often to 4 = Never. The mean rating for the sample was 1.92 (sd = 0.63), indicating that teachers sometimes felt well informed. Once again, this was not related to teaching experience, since no significant correlation was found between the teachers' responses and their years of teaching experience ($R2 = -.0019$, ns).

Question 6: When you are teaching a new science topic do you find that children have their own ideas about the topic which are misconceived or partially incorrect?
Responses were on a scale from 1 = Always to 5 = Never. Teachers thought that children sometimes had their own ideas, the mean rating was 2.66 (sd = 0.64) where 2 = Often, 3 = Sometimes.

Question 8: What effect would you say a misconception can have upon the child being able to understand a new concept?
Teachers were able to respond on a scale of 1 to 5, where 1 = Very helpful and 5 = Very obstructive, or 6 = Other, where they were asked to give details. 110 teachers responded using the 1 - 5 scale, with a mean rating of 3.87 (sd = 1.25) where 3 = No Effect and 4 = Obstructive.

Teachers therefore did not think that children's' misconceptions were helpful in bringing about new understanding. These responses were not related to whether a teacher felt it important to find out about what the children already knew about a topic before teaching it, since their responses to this question did not correlate significantly with responses to question 3 ($R2 = -.0701$ ns).

Nor were they related to how well the teachers felt they were informed about children's pre-existing knowledge since their responses to this question did not correlate significantly with responses to question 4 ($R2 = -.0555$, ns).

This question also elicited a number of written comments, either in addition to the rating given or alongside the option 6.Other (please give details). These offered insight into the effects the teachers see a misconception as having on the teaching process and hence warranted further qualitative consideration.

Several teachers who thought a misconception could be helpful, (i.e. rated 2 or above) said it was because it could be used as a starting point for a discussion or investigation. One teacher said, 'It causes children to think and give reasons for why they think something, leading to deeper investigations'. Having a misconception was therefore thought to ensure the child would be cognitively active during an investigation, and would be forced to make their ideas explicit. Some of the teachers qualified their positive ratings by commenting on the fact that children may still be reluctant to give up their misconception. 'They have to investigate but sometimes they still think they are right' observed one teacher, 'Some find it hard to change their ideas' said another, whilst another pointed out that 'It depends on how receptive the child is to questioning their own thinking'.

Receptivity to new ideas was also a theme among those teachers who rated misconceptions as having a more negative effect and being 'Obstructive' to the learning process (rated 4 or above). 'These ideas are hard to change' stated one teacher, 'Slows progress' and '..it can take longer for them to understand a new concept' said others, whilst another observed 'Teaching is easier than 'unlearning' a misconception' suggesting that it is harder to get children with their own false beliefs to learn a new concept.

Hence there was clearly ambiguity about the role played by misconceptions in the classroom, with even the minority who rated them as 'helpful' qualifying their answers with comments about children's reluctance to give up their ideas. This was also reflected in the responses of those teachers who chose simply to comment rather than give a 1 to 5 rating. 'Helpful if discussed, obstructive if not dealt with' was one teacher's view of the effect of misconceptions, 'It might prompt a discussion..or might cause more confusion' was how another described the paradoxical effects of having a misconception. One implication of this is that teaching strategies need to be carefully employed if misconceptions are to have a positive, rather than a negative effect.

3. Questions about understanding of experimental method

The National Curriculum programme of study (Department for Education, 1995) states that pupils should be taught, at Key Stage 1, to turn 'ideas into a form that can be investigated' and 'to recognise when a test or comparison is unfair'. Given that this requires some quite abstract understanding of process, we decided to question teachers about children's understanding of the experimental method.

A number of teachers chose to mention this in their responses to Question 7 when asked for misconceptions. They stated that children thought of a fair test as being one where 'everyone got a turn' and found the strategy of controlling all variables whilst manipulating just one hard to grasp. Their responses to Questions 9 and 10 gave quantitative information about this.

Question 9: Science involves the carrying out of experiments. In your experience, by the end of Key Stage 1,how capable do you think most children are of recognising when a test is fair or unfair?

The response scale to this question was from 1 = Very Capable to 5 = Poor. The mean rating given by teachers was 3.09 (sd = 0.96) indicating that teachers thought most children were 'fairly good' at recognising when a test is fair or unfair.

Question 10: In your experience, by the end of Key Stage 1, how good do you think most children are at designing an experiment which is a fair test?

This question was designed to see if children achieved the stated aim of being able to turn their 'ideas into a form that can be investigated'. The response scale was from 1 = Very Good to 5 = Poor. The mean rating given by teachers was 3.74 (sd = 0.85) suggesting that they thought most children were 'fairly poor' at designing a fair test.

Question 11: How often in your teaching do you explicitly refer to this technique of scientific investigation (i.e. use of a fair test)?

The rating scale for responses to this question went from 1 = Very Often to 5 = Never. The mean rating from teachers was 2.52 (sd = 0.86), i.e. midway between 2 = Often and 3 = Fairly Often. This suggests that teachers did refer to the technique explicitly at times.

Discussion

Although there has been much theorising about misconceptions in science, little attempt appears to have been made to translate the theories into practical terms for primary school teachers. This paper started out by describing some empirical studies into children's naive theories of two physics concepts, balance and curvilinear motion. The RR model (Karmiloff-Smith, 1992) was invoked to explain how, in cognitive developmental terms, these naive theories are a feature of the process of conceptual change and have their roots in past experiences. This study set out to describe qualitatively the type of naive theories which, according to teachers, children hold in relation to specific science concepts in the National Curriculum in England. The importance of this information rests on increasing evidence that naive theories play a role in the acquisition of new concepts and that bringing a false belief to mind can assist in the process of change (Pine and Messer, in prep.; Kloos and Somerville, 1999). Questionnaire data fromprimary science teachers revealed some of the naive ideas which they believe children have and the many false science beliefs relating to Key Stage 1 curriculum topics.

The data confirm the view that children do not come to primary science lessons as a 'tabula rasa' but come with rich knowledge about their physical world based on their everyday experience, as Vosniadou and Ionnades (1999) proposed, although this rich knowledge is laden with over-generalisations, heuristics and misconceptions. This survey from over one hundred teachers revealed 130 false beliefs about science concepts which are taught in primary school. Examples covered all aspects of the primary science curriculum, including life processes and living things, materials and physical processes. It also confirmed that teachers believe abstract concepts, such as those involving forces and electricity are hardest for children at this age. Of the topics sampled, the teachers rated almost one third of them as being of above average difficulty for the children. However, of significant importance here is the fact that the data relate to teachers' perceptions about the topics children find difficult. Given the robust nature of misconceptions is science, and the fact that over 70% of the respondents were not science specialists, this could be a reflection of the teachers' own difficulties with certain topics.

The teachers surveyed felt it was important to find out what a child already knew about a topic before they taught it, the cornerstone of a constructivist approach to teaching. This was indicated by a fairly high mean response to the question 'When you are teaching a new science topic, how important do you think it is to find out what children already know about the topic?' where the mean response was between 'important' and 'very important'. Teachers described a range of methods used to find out what children already know, including discussion, brain storming, past records, questioning, testing and predicting. However, this does not tell us whether finding out what children already know involves searching for their correct notions about the topic, or actively probing for misconceptions. For when the teachers were asked, 'What effect would you say a misconception can have upon the children being able to understand a new concept?" the mean response was on the negative side of the scale, close to 'Obstructive'. The implications of this are that teachers may think false beliefs get in the way of the teaching process, and are best ignored or squashed as quickly as possible. This is reflected in current teaching practise, where making false beliefs explicit is rarely part of the instruction process. However, findings are emerging which suggests that calling children's naive theories to mind, and making them explicit, can help the acquisition of new concepts.

In our own work with six and seven year olds learning about balance we have found that children who are able to express their belief about things balancing in the middle make better progress than those whose ideas are not made explicit (Pine and Messer, 2000). Hence a non-verbal naive theory may be more obstructive than a verbal one. We have also found (Pine and Messer, in prep.) that providing a correct demonstration is more effective if it takes place immediately after a child has demonstrated their own error-prone thinking (a form of contrast modelling also purported to underlie language learning, see Saxton, 1998). In the domain of learning about density, Kloos and Somerville (1999) have found that four and five year old children who are given the opportunity to call to mind their initial understanding about sinking, before being presented with new information, are more likely to change their faulty belief than children who are not given this opportunity. They argue that calling to mind an existing belief provides an over-arching structure or framework that makes the new information meaningful and allows children to realise its relevance to certain tasks. By activating an existing representation the child is primed to receive new information, with the existing knowledge structure functioning as a framework for organising new evidence.

These studies come out in support of the view that conceptual change in science is not a process where old representations are supplanted by new, correct conceptions delivered by a teacher (as Posner et al. 1982). As many recent researchers have claimed (Clement et al. 1989, Karmiloff-Smith, 1992; Schauble, 1996; Vosniadou and Ionnades, 1998) science learning involves the gradual enriching and restructuring of the child's pre-existing knowledge. In the model proposed by Karmiloff-Smith this restructuring process is accompanied by increased conscious and verbal access as conceptions become more explicitly represented. But it is also during the course of this explicitation process that naive theories, or Level E1 representations, may be formed. These theories, as we have shown, may be verbal or non-verbal with the latter being particularly resistant to instruction.

The presence and robustness of naive theories in young children also suggest that the children will derive less benefit from experimentation and demonstration, since they will only observe those aspects which support their own theory. The implications of this are that, when demonstrating to young children, it may be necessary to use their ideas as the starting point or to design experiments which directly address their false beliefs. Although some of the children's ideas identified in this study arose from linguistic confusion or misconceptions, our previous work (e.g. Pine & Messer, 1999, 2000) leads us to believe that the overgeneralisations (e.g. large objects are heavier than small objects) may prove most resistant to teaching since, being partially correct, they will at times be reinforced by confirmatory evidence.

Our conclusions from this work is that children do hold many incorrect ideas about the science topics which are on the primary curriculum. These ideas are of considerable importance, and cannot be ignored, in the learning process since they are the foundations upon which new knowledge is built. Clearly, teachers need to place as much emphasis on children's wrong ideas as on their right ones, if they are to effectively bring about conceptual change in science. The naive theories and false beliefs which children hold about primary science concepts identified in this paper provide just the starting point for that shift in emphasis. If teachers are better informed about the types of false beliefs children are likely to hold they will be quicker and better at identifying them, at helping children call them to mind and make them explicit and at incorporating them into the process of conceptual change. What the data fail to show is how many of these naive beliefs held by children are implicit, or non-verbal, since these too need to be addressed and more research into children's implicit knowledge is required. Finally it must be remembered that, in common with many adults, teachers too can have misconceptions about science and that children's ideas may be a reflection of this.

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Table 1: Science statements rated in terms of difficulty by teachers of children at Key Stage 1 (1= Very Easy, 2= Easy, 3= Average, 4= Difficult, 5= Very Difficult) and some examples of children's false beliefs.

Table 2: Other areas of the curriculum where teachers identified misconceptions:

Science statement/concept	Frequency (no. of times cited in response to Question 2)
The sun stays still and the earth moves around it; the movement of the earth and planets.	8
Anything abstract; outside child's own experience.	7
Condensation and evaporation; the difference between steam, smoke and mist.	6
The moon is not a source of light.	6
Floating and sinking/density.	5
Forces and electricity.	5
Living/non-living classifications.	5
Sound produces vibrations; high and low pitches.	4
Magnetism.	4
The difference between man-made and manufactured.	3
Air is inside and all around us, empty containers have air in them.	3
Things can be dead which were once alive.	3
That heated/melted materials can become solid again but some changes are irreversible.	2
Shadows/reflections.	2

Appendix A: QUESTIONNAIRE FOR TEACHERS OF KEY STAGE 1 SCIENCE

This survey is aimed at finding out about how children learn Key Stage 1 Science topics and teachers' experiences are a valuable source of information. We are particularly interested in which KS1 science topics children find most difficult and what children already know about these topics before they encounter them in the classroom. The questionnaire is anonymous and the information gained will help to build a research programme into how children learn about their physical world.
We would appreciate it if you could spend a few minutes answering the questions over leaf. Your co-operation is very much appreciated. Thank you.

Q1. Please look at these statements which express some of the ideas taught to children at Key Stage 1. Based on your teaching experience, we would like you to indicate how difficult you think each of these ideas is for children to understand.
Please go through the list quickly and circle your immediate response.

SCIENCE STATEMENT	LEVEL OF DIFFICULTY FOR CHILDREN 1 Very easy	2 Easy	3 Average	4 Difficult	5 Very difficult
Electrical devices will not work if there is a break in the circuit	1	2	3	4	5
Darkness is the absence of light	1	2	3	4	5
Forces can make things go faster	1	2	3	4	5
Forces can make things slow down	1	2	3	4	5
Forces can make things change direction	1	2	3	4	5
Forces can change the shape of objects	1	2	3	4	5

There are many sources of sound	1	2	3	4	5
Sounds get fainter as they travel away from the source	1	2	3	4	5
Sounds are heard when they enter the ear	1	2	3	4	5
Some materials (e.g. wood, rock) are found naturally	1	2	3	4	5
Some materials are man-made	1	2	3	4	5
Some materials can be changed in shape	1	2	3	4	5
Ice is frozen water	1	2	3	4	5
Babies grow into adults	1	2	3	4	5
Growth is gradual and continuous	1	2	3	4	5
Plants need light and water	1	2	3	4	5
New plants are produced from a plant's seeds	1	2	3	4	5
Shadows are places sun light cannot reach	1	2	3	4	5
Steam can change back to water	1	2	3	4	5
Heavy and light objects of the same shape fall at the same speed	1	2	3	4	5
Large and small objects can weigh the same	1	2	3	4	5
A worm is an animal	1	2	3	4	5

Q2. Please look again at the list of statements in Q1. Are there any that you would add to this list which would be 'difficult' or 'very difficult' for children?

Q3. When you are teaching a new science topic, how important do you think it is to find out what children already know about the topic?

1. Very important 2.Important 3. Quite important 4. Not important

Q4. When teaching a new science topic, how often do you find you are fully informed about what children already know about the topic?

1. Often 2. Sometimes 3. Rarely 4. Never

Q5. What methods, if any, do you use to find out what children already know?

Q6. When you are teaching a new science topic do you find that children have their own ideas about the topic which are misconceived or partially incorrect?
1. Always 2. Often 3. Sometimes 4. Rarely 5. Never

Q7. Can you give an example of a common misconception children might have about a KS1 science topic?

Q8. What effect would you say a misconception can have upon the children being able to understand a new concept?

1. Very helpful 2. Helpful 3. No effect 4. Obstructive 5. Very obstructive
6. Other (please give details)

Q9. Science involves the carrying out of experiments. In your experience, by the end of Key Stage 1, how capable do you think most children are of recognising when a test is fair or unfair?

1. Very capable 2. Capable 3. Fairly good 4. Fairly poor 5. Poor

Q10. In your experience, by the end of Key Stage 1, how good do you think most children are at designing an experiment which is a fair test?

1. Very good 2. Good 3. Fairly good 4. Fairly poor 5. Poor

Q11. How often in your teaching do you explicitly refer to this technique of scientific investigation (i.e. use of a fair test)?

1. Very often 2. Often 3. Fairly often 4. Rarely 5. Never

Q12. How many years have you been teaching?
Q13. What is your subject speciality?
Q14. How many years have you taught KS1 Science?
Q15. Approximately how many children are in your school?
Q16. Please indicate the approximate percentage of children in your school who:
a) Do not have English as their first language. ....%
b) Are eligible for free school meals. ....%

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