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Author: **Leach, John; Driver, Rosalind; Millar, Robin & Scott, Phil**

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A range of interview-based instruments were designed to probe students' understanding of each of the features of interest. At least sixty students were interviewed in pairs at each of three ages (9, 12, 16). Responses were audiotaped and transcribed. Forms of reasoning were identified from the range of responses and used to code the transcribed interviews.

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Children's ideas about the nature of science from age 9 to age 16

John Leach[1], Rosalind Driver[1], Robin Millar[2], Phil Scott[1]

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ABSTRACT

It has been argued that a knowledge of the nature of the scientific enterprise may be important for students (a) to better understand the status of the concepts that they are being taught; and (b) because the nature of the scientific enterprise is itself an important curriculum goal in developing a scientifically literate society.

This cross-sectional study has been carried out to provide an initial map of the ideas that school students at different ages are likely to have about a number of features of the nature of science including: the purposes of science; the nature of theory, and its relationship to evidence; and science as an enterprise, and how it relates to society.

A range of interview-based instruments were designed to probe students' understanding of each of the features of interest. At least sixty students were interviewed in pairs at each of three ages (9, 12, 16). Responses were audiotaped and transcribed. Forms of reasoning were identified from the range of responses and used to code the transcribed interviews.

This paper describes a number of the probes used, their administration and analysis. Broad trends in the results across ages from these probes are discussed and educational implications are identified.

1 INTRODUCTION

The purpose of this study is to investigate the ways in which young people of school age conceptualise what science is about. This includes studying their perceptions of the ways in which scientific knowledge is characterised and distinguished from other forms of knowledge, the ways in which new knowledge is developed, and the social processes scientists engage in when establishing knowledge claims.

While extensive research has been undertaken into young peoples' representations within particular conceptual domains in science (e.g. light

[1] Children's Learning in Science Research Group, C.S.S.M.E., University of Leeds, Leeds LS2 9JT, UK.

[2] Department of Educational Studies, University of York, Heslington, York YO1 5DD, UK.

and sight, force and motion, photosynthesis, the nature of matter) there have been fewer systematic studies of what young people think the activity of doing science involves. Our interest is in finding out how young people in the UK characterise science and the activities of scientists and how these representations may differ over the school years.

A knowledge of the epistemology of scientific explanations, and how they differ from everyday explanations for natural phenomena, may help students in the process of making sense of scientific concepts in school science (Driver and Oldham, 1985; Solomon, 1992; Duschl, 1990). Young peoples' learning of science can usefully be viewed as children making personal sense of a socially validated body of knowledge (Driver *et al*., forthcoming (a)). The learner is likely to have everyday ways of explaining many of the natural phenomena that are the subject of scientific explanation, though the underlying epistemologies and ontologies of such everyday explanations may be different from scientific explanations. This is hardly surprising, as everyday explanations have different purposes from scientific explanations.

It has been argued that knowledge of the nature of science is an important curricular goal in itself due to the cultural significance of science (e.g. Miller, 1983). If a purpose of the school science curriculum is to develop understanding of the nature of science then it is important to know something of students' existing epistemologies in order to help them to see the different purposes of explanations in science.

Young people's characterisations of science and the activities of scientists are likely to be influenced by various factors including images communicated through the media, conversations with adults and peers and of course the portrayal of science through school science lessons. These influences may impact on young people in varying ways during their schooling. We anticipate that young people of different ages may therefore have different views of aspects of the nature of science and that information about characteristic features of these representations and how they differ with age may be helpful information in planning appropriate science teaching. A cross-sectional study involving pupils aged 9, 12 and

16 was therefore conducted to provide an initial 'mapping out' of this aspect of young people's thinking about science.

2 FOCUS OF THE STUDY

It was obviously important at the beginning of this study to identify those features of science as an activity which should be focused on in our enquiries with young people. In making this decision we drew on contemporary perspectives on the philosophy and sociology of science. We also considered the arguments being put forward about those features of the scientific enterprise which are claimed to be important for the development of scientific literacy. For example, ideas about the purposes of science and science as an enterprise have been identified as important features of scientific literacy (e.g. AAAS, 1989). In addition, it has been suggested that an ability to think about the nature of theories and their relationship to evidence may help pupils in learning about particular scientific concepts (Driver and Oldham, *op. cit.*;*cit.*). Our decisions were thus informed by both philosophical and educational considerations, and we identified three main aspects of the nature of the scientific enterprise to focus on in the study: (a) questions relating to the purposes of science; (b) questions relating to the nature of scientific knowledge; and (c) questions relating to science as a social enterprise. We further identified a number of features of each of these aspects as a guide in preparing appropriate diagnostic instruments (see Appendix 1 for the list of aspects and component features).

This paper addresses the second aspect only, namely students' representations of the nature of scientific knowledge.

3 METHODOLOGICAL CONSIDERATIONS

A range of different foci of attention have been taken in previous studies in this area. In some previous studies, researchers have been interested in the ways in which young people conceptualise the work of scientists. The methods employed have required subjects to talk or write about their perceptions of the work that scientists do, the motivations for this work and the processes used by scientists for generating and evaluating explanations. In other cases, studies have acknowledged the likelihood that although young people may have little first hand knowledge of the work of scientists they do have more knowledge of the work that they undertake themselves in school science. Such studies have focused on young people's explicit understandings of the work that they themselves undertake in learning science. A third type of study addresses pupils' implicit ideas about the purposes of science and the role of theories and evidence by making inferences about their reasoning while engaged on specific tasks. In this way information about students' perceptions is obtained from their actions rather than through their overt statements.

Young peoples' ideas about the purposes of science have been studied by Carey *et al*. (1989) and Aikenhead *et al*. (1987). Carey *et al*. addressed 12 year old pupils' views of the purposes of science during a teaching programme designed to promote understanding of science as involving hypothesis generation and testing. Aikenhead *et al*. used a written survey with a large sample of Canadian high school graduates (aged 16 to 20) independently from any teaching programme. These studies suggest that students in schools and colleges tend to see the purpose of science as being the manufacture of artifacts, usually for the enhanced wellbeing of humankind, with little or no reference to theory or explanation. When the generation of explanations is mentioned as a purpose for science, these are often seen as simple mechanistic explanations, rather than more general explanatory theories.

Aikenhead *et al*. also reported that the conjectural nature of scientific theories tends not to be appreciated by students. Rather, they tend to view theories as emerging from observed features with changes in scientists' theories over time coming about through improvements in instrumentation (e.g. more powerful telescopes). Carey (1989), Songer and Linn (1991) and Larochelle and Désautels (1989) have reported similar views about scientific theories amongst pupils in the secondary years, in the context of theories encountered in their own learning of science.

The way in which young people see the relationship between theory and evidence in scientific enquiry has prompted some controversy. In a classic study to describe differences between how very young children and older children use theories as tools in solving problems, Karmiloff-Smith and Inhelder (1974) noted a tendency for older children to gather evidence systematically in the context of a theory, and to evaluate the theory in the light of such evidence. Karmiloff-Smith and Inhelder suggested that counterexamples alone did not produce theory change in this case, a claim also made by Rowell and Dawson (1983) in a study on the use of counterexamples to promote conceptual change in explanations of floating and sinking. In addition, Rowell and Dawson noted that children's *espoused* views about how they tackle problems involving theory and evidence are different from the *actual procedures that are used*.

A number of studies address the question of whether differences between younger and older pupils' ability to relate theory and evidence can be accounted for in terms of the development of general reasoning skills, or an increased ability to deploy particular reasoning strategies in certain contexts. Kuhn *et al*. (1988) describe a number of experiments where children and adults evaluate 'theories' in terms of particular data items. The theories that the students were asked to evaluate in this study were set in everyday contexts and were independent of scientific subject matter. The authors note an increased tendency for older subjects to think about theories and the evidence that relates to them as separate entities, and they account for this in terms of the development of general reasoning skills.

This explanation is questioned by Samarapungavan (1991). She conducted a study in which children between 6 and 11 were presented with competing theories to explain phenomena in domains where children are likely to have strong prior ideas (the causes of day and night) and domains where children are likely to have minimal prior experience (colour change and the use of indicators). Little difference with age in the children's ability to distinguish between theories that differ on the parameters of empirical consistency, logical consistency, generalisability and use of *ad hoc* explanation was noted, the percentages achieving success being in the region of 80% on each parameter at each age. This was interpreted as indicating that young children are able to use sophisticated reasoning in contexts where they are encouraged to do so. Furthermore, she argues that the differences between younger and older pupils in Kuhn *et al*.'s study cannot, therefore, be accounted for in terms of the development of general reasoning skills with age but rather in terms of an increased ability to deploy such reasoning in the context of particular knowledge domains.

In the above studies, claims are made about changes with age in students' understanding of the nature of science, in the context of their own work in school science (e.g. Carey *et al., op. cit.*) and the work of scientists (e.g. Aikenhead *et al., op. cit.*). Methodologies rely on both students' explicit responses to direct questions (e.g. Carey *et al., op. cit.*), and inferences based on their approaches to particular tasks (e.g. Kuhn *et al., op. cit.,* Samarapungavan, *op. cit.*). There are also claims as to possible underlying mechanisms for this change (Kuhn *et al., op. cit.,* Samarapungavan, *op. cit.*).

In this study we have used a cross-sectional design in which groups of students, of different ages, work together on various tasks. Inferences are then drawn about students' construals of various aspects of the nature of science on the basis of their discussions on the tasks, and answers to particular questions. To this end our aims are rather different from those of Kuhn *et al.* and Samarapungavan in that we are not assessing whether students are *able* to use particular forms of reasoning but rather documenting the *conceptualisations* of particular entities such as theories, and activities such as experimentation, used by students in various contexts.

Data from such a study provides insights into likely representations of the nature of science at the population level; no conclusions can be drawn about individual pathways in learning, nor the mechanisms of change (Leach et al., forthcoming).

4 DESIGN OF RESEARCH INSTRUMENTS

Seven research instruments (termed 'probes') were developed, with the intention of providing activities through which inferences could be made about students' views about the nature of science. (Brief descriptions of each probe can be found in appendix 2.) We wanted to see how students treat theories and evidence in conceptually rich contexts such as those encountered in school science, rather than the more artificial and detached correlational hypotheses used by Kuhn *et al.* (*op. cit.*). Each probe is therefore set in a particular conceptual domain from school science, and administration is structured to allow students time to make sense of the conceptual domain before addressing the more complex metacognitive issues that are the main focus of the task.

We were interested in three main strands of children's epistemological reasoning: (i) which domains they consider proper for scientific inquiry; (ii) their understanding of the nature of scientific knowledge; and (iii) their appreciation of science as a social enterprise.

Six of the seven probes were designed as interviews for administration to pairs of students. The tasks were presented in a relatively standardised way. One probe, Scientific Questions, addresses students' ideas about the domains of science. They are asked to classify a number of enquiries as to whether scientists would be interested in them or not, giving their justification. Six probes, Experiment, Belief, Theory Stories, Real and Imaginary, and Theory and Evidence, all address student's representations of the nature of scientific knowledge. On the Experiment probe, students classify a number of activities as experiments or not experiments, and explain their classification. The Belief probe presents theories to students that are familiar from school science lessons. Students have to say whether they believe the theories, and explain their reasons for believing each one. The Theory Stories probe presents three stories to students in which the word 'theory' is used. Students are asked to explain what they understand by the word, and how each theory could be tested. The Theory and Evidence probe is more formally structured. Students have to comment on whether particular pieces of evidence support a chosen theory. The Real and Imaginary probe presents students with cartoons depicting discussion between two school students about the status of electric current, food webs and gravity as real or conjectural entities. Students are asked to state their views on the discussions in the cartoons.

The last probe, 'Closure of Debates', is rather different in design in that the focus is on students' explanations of how scientists reach agreement on problematic issues rather than on their own explanations. This probe was used only with 16 year old students.

The remainder of this paper describes findings from two of the probes relating to students' representations of the nature of scientific knowledge, 'Experiment' and 'Theory Stories'.

4.1 The Experiment probe

The Experiment probe was designed to examine the sorts of activities that learners consider to be experiments, and their implicit and explicit ways of characterising experiments.

We decided to present pupils with descriptions of people involved in a number of activities which involve collecting information in the context of different practical activities. A range of activities were selected to cover a spectrum ranging from those with no theoretical or investigational component, to activities in which data are collected in order to evaluate a stated theory.

We imagined that a number of factors might influence pupils in deciding whether a particular activity is an experiment or not, such as the context of the activity and the type of idea being investigated. For example, school science may encourage learners to refer to all activities involving equipment as 'experiments', even in cases where there is no investigative component. Pupils may, however, differentiate between activities with no investigative component and activities to generate and test generalisations and hypotheses, or to test the empirical consistency of explanatory theories.

As well as different types of investigative and non-investigative activities, the activities selected involved different contexts. Some contexts had close associations with school science, whereas others had little association with school science.

Subjects were presented with a number of cards on which were written the descriptions of the activities. They were asked to classify each activity as an experiment or not an experiment, or state that they were not sure, explaining their reasons. Subjects were then asked whether it is important in classifying activities as experiments if someone already knows the answer. They were also asked whether scientists have an idea of what is going to happen before they start experiments. The cards used on the Experiment probe are listed in Appendix 3.

4.2 The Theory Stories probe

In this probe, we were interested in the ways in which students conceptualised the nature of theories that may be familiar to them from school science lessons. Are they familiar with the word 'theory', and if so what meanings do they attribute to the word? Do they show evidence of thinking of the theories as models? Do they show evidence of thinking about theories as entities separate from the phenomena that they explain? How do they seem to relate theories to evidence, in the context of familiar natural phenomena?

In order to provide a context for subjects to talk about theories, a number of short stories were written, involving children talking about a theory (and the evidence that might support it). It was necessary to pilot stories using a number of contexts, with the aim of selecting contexts familiar to subjects in the 9 to 16 age range. Three stories were finally selected, relating to the rusting of iron, the behaviour of air on heating and the germ theory of decay. The text of the stories, and the questions asked about them, can be found in Appendix 4.

The ‘Rust’ and ‘Germs’ stories were structured so that a phenomenon was observed by a pair of characters, and then one character gives a possible explanation for the phenomenon, using the words ‘I have a theory about that...’. The interviewer then asks subjects what they think the character means by ‘a theory’, and whether the subjects have any idea what the theory might be. The story continues with the character’s theory, and at the end of the story the interviewer asks subjects whether the characters can be sure that the theory is correct, and what could be done to prove that the theory is correct.

The story about the behaviour of air on heating, ‘Balloons’, was slightly different in structure. Characters in the story outline two different theories to explain why a balloon which is fixed over the end of a glass bottle inflates when the bottle is heated. As well as asking subjects about the meaning of the word ‘theory’, and whether the characters can be sure that the theory is correct, the interviewer also asks which theory is best to explain the evidence available in the story.

The contexts of the three stories are different in a number of ways. The phenomena of rusting and milk going bad are familiar to subjects in the 9 to 16 age range. During piloting, we noted that the explanations presented for these phenomena in the stories are also familiar to most 9 to 16 year olds, as a result of everyday ‘folk knowledge’ and formal science teaching. This allowed us to determine how subjects conceptualised theories and evidence in two familiar contexts, and the extent to which subjects view the contexts as appropriate for using formal science knowledge.

The phenomenon of a balloon fixed over the neck of a glass bottle being inflated by heating the bottle is less familiar to subjects. However, subjects are familiar with hot air balloons and the explanation for why hot air balloons float in terms of hot air rising. In addition, the balloons story is located in school science teaching. The reason for using this context was to examine the type of reasoning used about theories and evidence when school science is more strongly cued. In addition, evidence about the explanations for the balloon rising is presented systematically in the story, and questions can then focus more directly on the relationships between theories and evidence.

The interview began with a brief introduction which explained that we were going to look at some short stories all about theories. The order of stories used was the rusting story, then the balloon story, and finally the germs story. The stories were printed and read aloud for subjects, the printed copy being on the table for them to follow. The printing had been planned so that interviewer's questions came at the end of a page, and subjects answer before seeing what comes next in the story. In some cases, where subjects had very limited or naive ideas about the meaning of the word 'theory', the question was not asked for all three stories. When subjects were not familiar with the word 'theory' the interviewer continued, referring to 'Brian's idea' or 'the idea that salty water makes the nails go rusty', for example.

5 DETAILS OF SAMPLE

Approximately 30 pairs of students were interviewed at ages 9, 12 and 16 for each probe (see Table 1). Subjects were selected from 6 primary (5 - 11 years), 2 middle (8 - 13 years) and 6 high (11 - 16 or 18 years) schools in low to middle income areas around an industrial city in the North of England. Pairs of students were selected by their class teachers (primary and middle) or science teachers (secondary) as being likely to engage in discussion together, and representing a range of ability within the school. All interviews were conducted by one of two interviewers.

Details of the number of interviews at each age on each probe are shown in Table 1:

TABLE 1: DETAILS OF SAMPLE FOR EXPERIMENT AND THEORY STORIES PROBES

Age:	Number of pairs: Experiment probe	Number of pairs: Theory Stories probe
9	31	31
12	32	28
16	33	32

6 METHOD OF ANALYSIS

The interviews were audiotaped and transcribed in full. Transcripts of interviews were examined, and common features in students' responses to questions and discussion were noted. Coding schemes for each probe were then produced and checked against the transcripts, adding or amending categories as required. The coding scheme is thus ideographic, being based on features of students' responses, rather than a normative view of the subject matter.

As the transcripts are a record of a discussion between an interviewer and two students, it was decided to code particular features raised by students in the discussion, rather than the responses of individual students. In some cases, it was not possible to attribute a particular argument to an individual student as both students were involved in articulating a point, or alternatively one student agreed with a point raised by the other. In such cases only one code was allocated for the feature. In cases where students expressed different or contrasting views, a code was allocated for each view expressed. Each interview may therefore contain multiple codes.

Each transcript was coded by one of two coders. For each probe, a subset of transcripts were coded independently by both coders, and any discrepancies were discussed. In some cases, it was necessary to recode the transcripts with respect to particular aspects in the light of these discussions.

7 RESULTS

Results for both the Experiment and Theory Stories probes can be reported at a number of levels:

- How did the students construe the conceptual context of the activity? For example, how did they make sense of each activity in Experiment, and each Theory Story?
- What features of reasoning about the nature of scientific knowledge can be identified from the transcripts? Were these features bound in particular contexts, or were they more widely noted?
- Were there any age-related changes in features of reasoning noted? Were these changes bound in particular contexts, or were they more widely noted?

Features of reasoning noted for each probe, and age-related trends in the use of these features, are described in the following sections. Common features of reasoning about theories and how they relate to evidence, as noted in the Experiment and Theory Stories probes, are also described.

7.1 THE EXPERIMENT PROBE (APPENDIX 3)

Analysis was designed to answer the following questions:

- What sorts of 'finding out' do students think is involved in experiments?

  It may be that they acknowledge that the person in the Post Office context is 'finding out' which stamps are required, but that this sort of finding out is different from the finding out involved in hypothesis testing on the dissolving context.
- Do students understand the type of 'finding out' in an activity in the same way that we intended in drafting the example?

  For example, students may think that the purpose of the activity described in the Balloon context is to inflate the balloon in an ingenious way, rather than to test which one of two theories is best at explaining the phenomenon.

- Do students see the context of an activity as influencing whether it is an experiment or not?
  For example, they may think that the same kind of 'finding out' is involved in the Cake and Crystal contexts, but state that the Cake activity is not an experiment but the Crystal context is, as it is carried out in a school science laboratory.

We do not take the view that one meaning of 'experiment' is inherently superior to another, but rather that certain meanings are more appropriate in particular contexts. Students' responses were coded at a number of levels. At the first level, a record was made as to whether each context was classified as an experiment, not an experiment or the subjects were not sure. In practice, a variety of justifications for these classifications were made by subjects, and the second level of coding aimed to group similar justifications. The third level of coding aimed to draw together features of responses across the contexts. What sorts of reasoning were drawn upon in deciding whether particular activities are experiments? What differences did students note in the type of finding out involved in the contexts? What meanings for the word 'experiment' were used in classifying the contexts? Were these meanings used consistently across the contexts?

7.1.1 Different characterisations of investigative activity made by students

Students were presented with a number of activities which involved different types of investigative activity (see appendix 3). The Cake and Crystal activities both involve following instructions and have no investigative component. The Post Office and Radio activities involve 'finding out' with a minimal theoretical component: weighing a parcel or a lay person finding out why a radio will not work. The Paper Towel activity involved finding out which paper towel is best at mopping up water, suggesting some sort of fair testing model requiring little theoretical background. The remaining activities, Rain, Dissolve, Conduct and Balloons, involved using empirical evidence to evaluate a generalisation, hypothesis or theory.

We were interested in how students conceptualised the ‘finding out’ involved in each of these activities, and whether each type of ‘finding out’ was seen as an experiment by the students (see next section). A number of different features were noted in students’ representations of the ‘finding out’ involved in the activities:

a) *Activity with no finding out*

A number of students suggested that activities such as Cake and Crystal involve no finding out:

(The activity is classified as an experiment)

P *Well, she's got all the apparatus and she's mixing it up like she's doing an experiment.*

I *Okay.*

P *The cake is the result.*

(Cake age 16)

(The activity is classified as not an experiment)

P1 *Well, because if they are taking it from a recipe, they already can read what they are going to do, so it shouldn't be an experiment because someone has already done it for them.*

(Cake age 9)

Comparison of the above examples shows that in both cases the activity is seen as involving a procedure of mixing ingredients. In one case, however, this is seen as an experiment whereas in the other case it is not.

In addition, activities such as Balloons were often described as involving making a phenomenon happen by ingenious means, rather than as using empirical evidence to evaluate the explanations given:

P1 *That's an experiment 'cos (...) there's a balloon there what's hot and there's a bottle there that's..*

P2 *All the air goes in the balloon and it'll go up.*

(Balloons age 9)

b) Activity involving 'mechanistic' investigation

Many of the activities were described by students as involving some sort of low level 'finding out'. For example the Cake activity was often described as involving finding out whether a recipe works:

(The students have classified the activity as an experiment)

P1 It would be kind of because you wouldn't know exactly how it's supposed to turn out. It could turn out just slightly different. (...) I suppose if it were your first time but like if you've made a cake before following a recipe ......

P2 It could be if like the first time was a bit different and this time was a bit different and ... they'd get two different like answers on, or it comes out wrong.

(Cake age 16)

Activities such as Paper Towel, Dissolve, Rain and Balloon were often described as involving the comparison of two or three discrete states rather than as evaluating a generalisation, hypothesis or theory in terms of empirical evidence. The Balloons activity, for example, was described as involving testing whether the balloon inflates best when the bottle is the right way up or inverted:

I Yeah right okay. And the balloons and air one. What was it about that that made you decide it was an experiment?

P2 Well, finding different ways to sort of get the balloon heated up (...) rise..

I Right so it's different ways of getting the balloon to rise.

P2 Yeah.

(Balloons age 16)

It should be noted that the Paper Towel activity does not, in fact, involve evaluating a generalisation, hypothesis or theory in terms of empirical evidence.

c) Activity involving 'evaluative' investigation

In analysis we have termed responses which give a clear indication that the activity involves collecting evidence to test a generalisation, hypothesis or theory 'evaluative'. Examples of such reasoning would be students who describe the Conduct activity as involving testing many metallic and non-metallic materials to see whether the described generalisation is true, or students who describe the Balloons activity as involving testing which of the two explanations best explains the behaviour of the balloons at different orientations:

(The students have stated that the activity is to do with finding something out)

I *What he's trying to find out?*

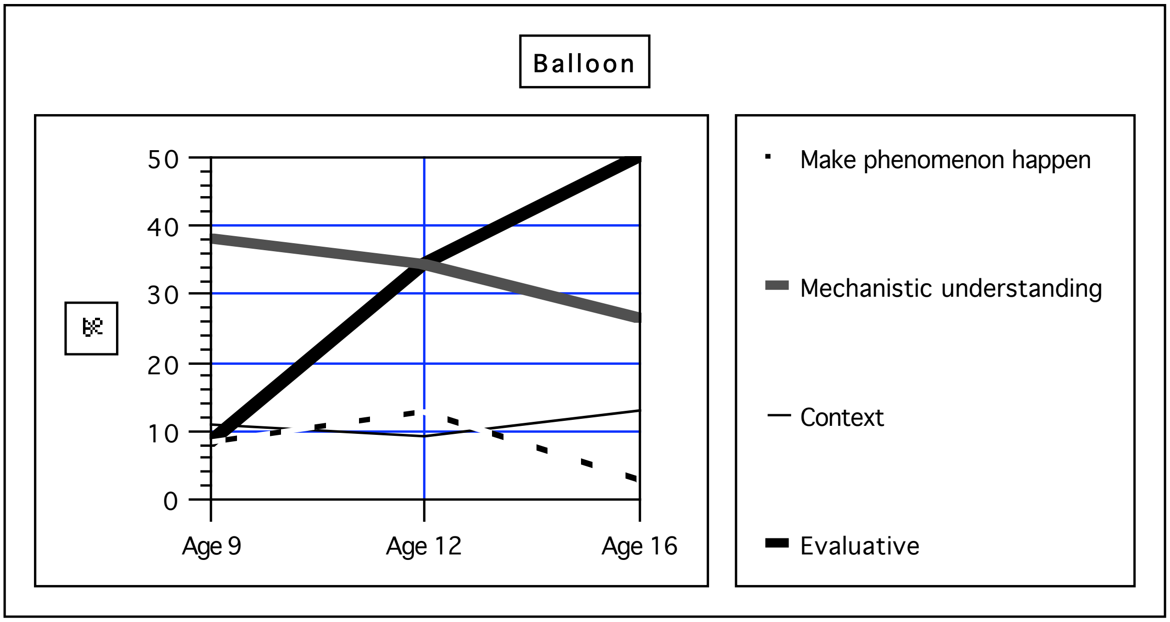
P *If it blows up the balloon then air expands when it's hot, not ... not rises.*

(Balloons age 16)

Age-related trends

There is a marked trend for older students to describe the Rain, Conduct, Dissolve and Balloon activities in terms of evaluative investigation (χ^2 test, $p<0.0001$). Corresponding decreases in other views of the investigative nature of the activities can be seen, though these trends are often not so marked. Indeed, it is a feature of the data that in many cases differences in responses within an age group seem at least as great as differences between age groups.

The increase in describing the activities in terms of evaluative investigation is exemplified in the following graph, which shows the percentage of responses on the Balloon activity which conceptualise finding out in terms of: making the phenomenon of inflating balloons happen, comparing the balloon's ability to inflate at different orientations of the bottle (mechanistic understanding), associations of the context with school science and collecting data in order to evaluate the two theories:



7.1.2 Characteristics of activities used by students in identifying experiments

Having classified each activity as an experiment, not an experiment, or not sure, students were asked to justify their classificiation. Justifications tended to refer to three features, namely the nature of the procedure involved, the nature of 'finding out' involved in the activity and the context of the activity.

a) The nature of the procedure involved

The responses of many students suggested that certain procedures are involved in experiments, such as mixing substances together to make a new substance, writing results into a table or making an unusual or exciting phenomenon happen. In these cases, subjects' responses referred to the nature of the procedure involved rather than the investigative nature of activities as determining whether the activity is an experiment.

For example, in the last section we saw that some subjects say that the Cake activity is an experiment because ingredients are measured out and mixed, and the cake is the result. Similar arguments were used to classify the Crystal activity as an experiment.

It was also common for students who saw the Balloons activity as involving making a phenomenon happen in an unusual way to classify this as an experiment.

On the Rain activity, many subjects referred to the fact that results were collected and written into a table as indicating that the activity was an experiment. Such responses often did not refer to the reasons for collecting such data, or the uses to which it could be put in terms of evaluating the generalisation; collecting and displaying data were seen as the purpose of the experiment:

P Yeah, 'cause you've got to experiment and see how much rainfall there is, because that's how the weather reporters know it.
P They do it for the weather reports.
I Okay. When you say you have to experiment to figure out, what do you mean by 'experiment'.
P Graphs.
I Okay.
P To see how much it rained.

(Rain age 16)

b) The nature of 'finding out' involved in the activity

The most common feature of the activities used to classify them as experiments or not experiments was whether there is an investigative component to the activity, and the nature of the investigative component. A number of different types of investigative activities were identified by students (which were described in the last section), though students differed in opinion as to whether each type of investigative activity was involved in experimentation or not. For example, some students who saw the Cake and Crystal activities as not involving any sort of 'finding out' suggested that they are not experiments for this reason, whereas other students suggested that they were experiments for other reasons, such as the nature of the procedures involved or the association with school science (see next section).

The majority of subjects suggested that activities conceptualised as involving mechanistic or evaluative investigation were experiments. The exceptions to this were cases where subjects felt that the level of mechanistic investigation involved was too low for it to be an experiment:

I What was it about this one that made you decide it wasn't an experiment?
P1 It hasn't got a thesis.
P2 Theory.
I Haven't got a theory in?
P1 'Cos they don't know why it doesn't work.
I Don't know why it doesn't...
P2 They've set out to find out why it doesn’t work.

(Radio age 16)

c) The context of the activity

A number of responses referred to the context of the activity as being involved in determining whether the activity is an experiment or not. For example, activities having strong associations with school science were often classified as experiments due to this association, whereas activities taking place in more general settings were not classified as experiments for this reason.

Consider the Cake and Crystal activities. In terms of their logical structure they are the same - instructions are followed and a product is made. Crystals are normally made in a science lab., however, whereas cakes are normally made at home:

(Cake classified as not an experiment, crystal classified as experiment)
I This one you felt like it was an experiment if I remember right because you've done things like this in class before when you followed instructions like this. Can you tell me what's different in your mind between these two that makes this one an experiment, but you weren't sure about when it came to the cake?
P Well normally when you do an experiment ... using chemicals.

I Okay.

P But you're just using flour.

(Cake and Crystal age 16)

Similarly, students who justified classifying the Rain activity as an experiment by referring to the procedure as involving recording and displaying data seemed to be drawing on experience of activities in school science lessons.

Age-related trends

The background knowledge of subjects seemed to influence students' classifications of activities as experiments, and their conceptualisations of the 'finding out' involved in each activity. At age 9 a larger number of pupils were unsure how to classify activities, or were unable to explain their classification, than at ages 12 and 16. Examination of transcripts suggests that in some cases this is due to a lack of understanding of the conceptual background of the activity (such as the difference between air rising and expanding or the idea that particle size may influence rate of dissolving). Caution must therefore be exercised in interpreting age-related trends in subjects' abilities to relate explanations and evidence where there is little difference in results between 12 and 16 year olds.

In general, there were no age related trends in the extent to which students drew upon the procedure involved in activities in classifying them as experiments; typically, around 10% of responses on each activity referred to aspects of the procedure involved. In the case of the Rain activity there appears to be an increase in the number of responses referring to the process of recording data in a table in classifying the activity as an experiment, though this is not significant ($p<0.34$).

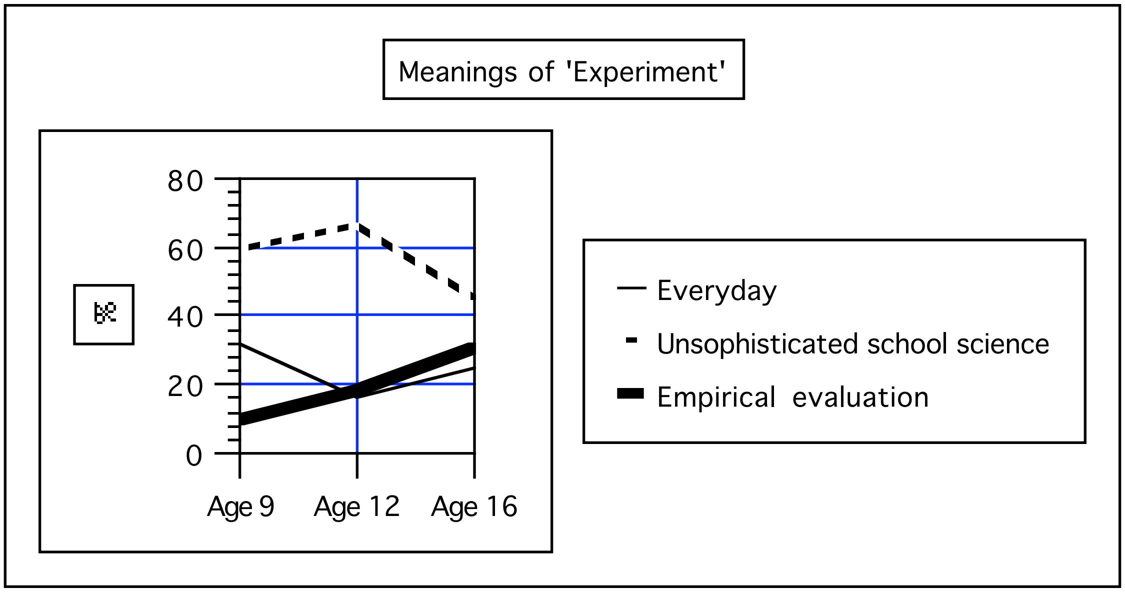
Age-related trends in the number of responses conceptualising the investigative nature of each activity in particular ways have been discussed in a previous section. Students who classified activities as experiments according to whether the activity involved evaluative investigation tended to do this across the range of activities; when aspects of context or procedure were drawn upon, this seemed to be more specific to the particular activity.

Three broad types of meanings for the word ‘experiment’ were identified:

1 Everyday ‘finding out’: This sort of use of the word ‘experiment’ involves a range of activities with some minimal investigative component. This would include finding out whether a recipe works, or finding out the stamps required to post a parcel.
2 Unsophisticated school science: This use of the word ‘experiment’ is peculiar to school science and includes any activity involving the use of chemicals and apparatus in a school science setting. It appeared that some subjects assumed that scientists perform similar activities in their work to those performed in school.
3 Empirical evaluative: This use of the word ‘experiment’ is more specific, and involves collecting empirical evidence in the context of a generalisation, hypothesis or theory.

There is clear overlap between these meanings. On the balloon activity, for example, some subjects may suggest that this is an experiment as two treatments of a balloon are being compared. This seems to draw on an unsophisticated school science view of experimentation: an empirical evaluative view would refer to empirical evaluation of the competing explanations for why the balloon rises. In the case of the paper towels context, on the other hand, it is more difficult to speculate as to the degree of sophistication underpinning a response that the activity is an experiment as different paper towels are being compared using a ‘fair test’.

With these caveats in mind, data were analysed to determine which uses of the word experiment were being used across the activities. The following graph shows changes in the use of these meanings with age:



There is an increase in the number of responses referring to experimentation as involving the evaluation of generalisations, hypotheses and theories in terms of empirical evidence ($p<0.001$). Most responses used an unsophisticated school science model of experimentation, and although this is used less between 12 and 16 ($p<0.006$), there is an increase in the number of responses classifying the Crystal activity as an experiment due to contextual associations with school science.

7.2 THE THEORY STORIES PROBE (APPENDIX 4)

Analysis was designed to answer the following questions:

- Are subjects familiar with the word ‘theory’? If so, what meanings do they ascribe to the word?
- How do subjects conceptualise the ‘theories’ presented in the story? Do they see them as separate entities from the phenomena that they explain? Do they see them as certain, or open to question, and for what reasons?
- Do subjects think that theories can be evaluated using empirical evidence, and if so, how?

Subjects’ responses were coded at a number of levels. In the first instance, categories were generated to summarise the use of the word 'theory' by subjects on each story, and the reasoning about theory and evidence used. The next level of coding looked for patterns across the three stories, focusing on the ways in which subjects talked about evaluating theories with empirical evidence.

A further level of analysis examined the ways in which students made predictions from the theories that hot air rises and hot air expands on the Balloons story, and the ways in which evidence was related to these two theories.

The focus of this probe is different from the Experiment probe in that students are asked explicit questions about their understanding of particular theories and the ways in which these theories could be tested. The ways in which the theories might be tested, however, are similar to those involved in some of the activities on the Experiment probe.

7.2.1 The meanings of 'theory' used by students

In each story, two characters discuss a phenomenon (railings rusting, a balloon inflating, milk going sour) and one of the characters says 'I have a theory about that'. Students were asked what they think the character means by 'a theory'. This question is first posed in the Rusting story; in the other two stories, students have already seen how the word 'theory' has been used on previous stories.

A number of students had not heard the word 'theory' before, or had heard it but had no idea what it means. Of the remaining responses, three main meanings for the word were noted:

a) General idea

Some students suggested that the word 'theory' is used by the character to indicate that they have 'an idea' or 'know something', with little indication from students as to what this idea might be:

I Do you know what 'a theory' means?
P A theory is an idea.

(Rusting age 9)

b) Exemplified idea

Along similar lines, some students gave an example of what the 'theory' might be in the given context, but gave no generalised definition for the word:

I What do you think Brian means by a theory when he says that?
P Does it mean that, it's because the water is making it rusty when it splashes up the wall.

(Rusting age 9)

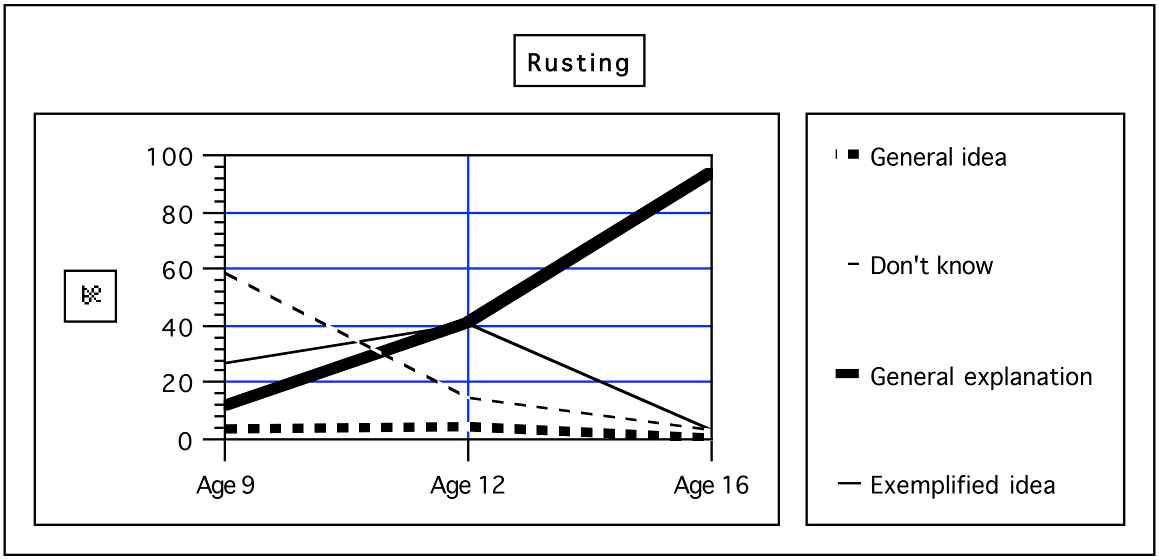
c) General explanation

A number of subjects stated that theories involve explanations or conclusions. Such responses, although involving an explanation as to what would happen in the context in question, also seemed to suggest a more general meaning for the word:

I Okay, what do you think Brian means by a theory?
P That he thinks he knows why it's happened .. why the railings at the seaside are a lot rustier than the ones at school.
I Uh huh. So by theory he means he thinks he knows why.
P A theory means make a conclusion.

(Rusting age 16)

The following graph shows how the use of these meanings for the word 'theory' changed with age on the Rusting story:



There is a significant trend for older students to suggest that theories involve explanations or conclusions in general terms ($p<0.0005$).

7.2.2 Suggestions made by students for testing theories

On each story, students were asked whether the characters could be certain that their theory was correct, and if they could not be absolutely certain, how they could test whether their theory was correct.

A number of students offered no ideas as to whether the characters could be certain that their theory was correct. In the remaining responses, four main types of argument were noted:

a) Empirical evaluation not relevant

In a number of cases, students argued that the characters could be sure that their theory was correct, making no reference to empirical testing. In some cases, subjects seemed to be drawing on everyday usage of the word ‘sure’ to mean ‘be fairly sure’. In other cases, subjects seemed to be arguing that the theory was common knowledge and therefore the characters could be sure that it is correct:

I Do you feel like you can be sure that that's what makes milk go off, that microbes grow better when it's warm?

P Yes. When you put them in the fridge it doesn't get rid of them. It just 'cause they don't grow as quickly.

(…)

I Okay. I'm really interested in that. So you can be sure (…) I'm wondering, what it is here that convinced you that you know that's what's happening?

P It isn't here. It's what I've learnt before in Science class.

(Germs age 16)

It should be noted that such responses may involve sophisticated reasoning and conceptualisation. It is not normal (or possible) in everyday life or school science to test all knowledge claims empirically. Similar reasoning was noted on the Experiment probe, where students suggested particular activities were not experiments as nothing new is being found out.

b) Variable evaluation

A number of students stated that the characters in the story could be absolutely certain that their theory was correct because they had shown that particular variables influenced the phenomenon in question. The problem was conceptualised by such students as hypothesis testing. Using very similar reasoning, other students stated that the characters could not be sure that their theory was correct as more hypothesis testing was required:

(The students have stated that they can be sure about the germ theory because they have already done experiments about it in school. The interviewer asks them to describe the experiments)

P Right. We had some milk left out and some milk put in the fridge and dipped our fingers in them and took down the results and that's what we ended up with. It went off quicker in the heat.

(Germs age 16)

I Can you think of any ways that they could check out that theory to find out if it's true?

P Do it at school.

I Do it at school. What sort of thing might..

P *Put some salt water on half of t' railings and half ... and see what happens.*

I *Oh I see the railings on the school?*

P *Yeah.*

(Rusting age 16)

Such responses do not differentiate between showing that particular variables affect an hypothesis and being certain of the causal mechanism of a phenomenon; if higher temperatures make milk go sour more quickly, then this *proves* that germs grow better in the warmth than in the refrigerator.

This reasoning seems similar to the mechanistic reasoning identified on the Experiment probe.

c) Relating variables to the event

Some responses reasoned about hypothesis testing as above, but acknowledged that there may be other factors that influence the particular phenomenon in question. Just because salt water influences the rusting of iron you cannot be certain that this is what caused the particular railings at the seaside to rust:

(The students have already described how particular variables could be tested. The interviewer asks them whether the characters in the story can be certain that their theory is correct)

P *Pollution and stuff could also sort of like add to the.. railing going rusty.*

I *Right. Okay so that's another thing that could be involved. So if they did the thing with the the nail the painted nail in salty water and it went rusty could they then be sure that it was the salt water?*

P *No 'cos they've got no proof really. That doesn't really prove it but they could probably assume that it's contributing at least.*

(Rusting age 16)

This reasoning seems similar to the evaluative reasoning noted on the Experiment probe in that students appreciate that evidence is being used to evaluate a theory.

d) Inherent uncertainty

A small number of students made comments which suggested an awareness that the issue of relating theoretical knowledge to real world phenomena is problematic. This was not articulated in a clear way, but was hinted at in some responses:

(The students are arguing for the air expanding theory over the air rising theory)

I Do you think that they can be sure that this theory's right?

P1 Yeah more or less.

P2 Think so.

I You don't look very sure I have to say!

P Well you can never be sure ... completely sure of anything but I mean this one more than the other one.

(Age 16 balloons)

Age-related trends

No clear age related trends were noted, mainly due to the high number of students at each age being unsure as to whether the characters could be sure that their theory was correct, and to the high number of responses at all ages stating that the theories were common knowledge (between 10% and 80% of responses). In general, around 50% of responses refer to variable evaluation, around 20% to relating the variables to the event in question. Graphs of results for each story can be found in Appendix 5.

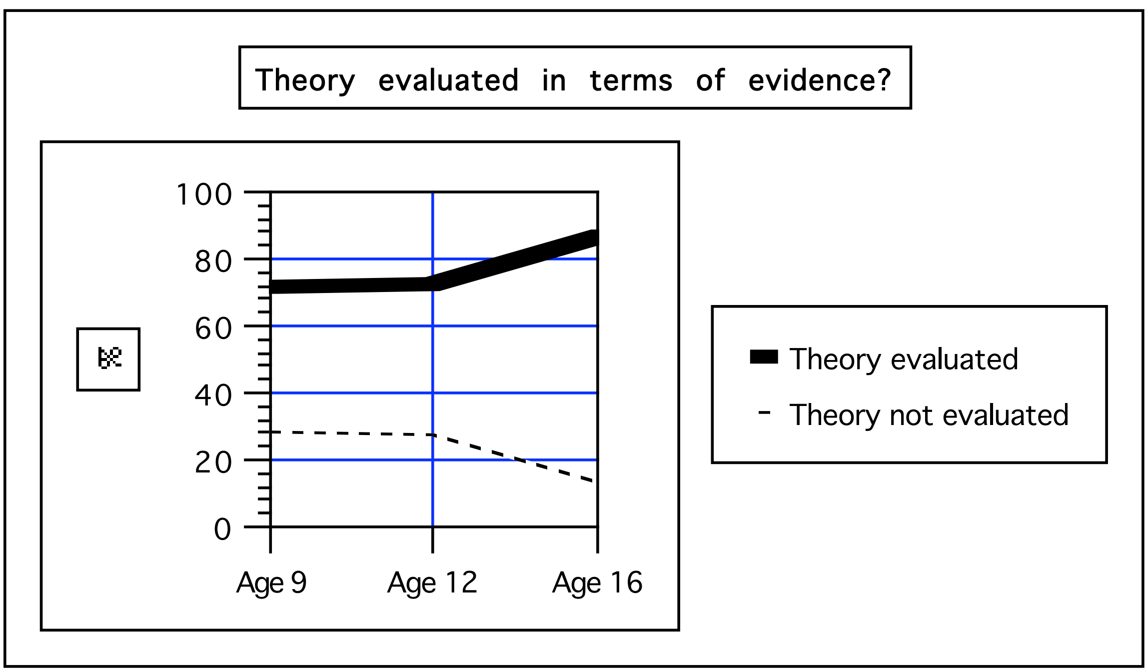
7.2.3 The coordination of theories and evidence by students

On the Balloon story, students were asked to predict whether the balloon would inflate when the bottle was inverted and to explain their prediction. Analysis of responses was complex, in that their initial conceptualisation of the problem influenced their predictions and explanations.

Some subjects seemed to agree with the explanation that hot air rising explains why the balloon inflates, but predicted that the balloon would still inflate on inversion. Their conceptualisation of 'rising' included 'rising and then falling when there is no available space'. Similarly, other students who initially predicted that the balloon would not inflate, explained why the balloon inflated using a similar modification to their theory. Other students stated that the evidence of the balloon inflating when the bottle was inverted proved that the rising theory was incorrect.

Other students made their predictions and explanations from a theory that hot air expands rather than rises, prior to this being introduced in the story, and this was true for significantly more older students than younger students ($p<0.045$). Such students did not encounter evidence that conflicted with their theory in the story.

These complex data were analysed in some detail, and in the end responses were classified into two categories: those involving evaluation of either theory using the evidence in the story, and those not involving theory evaluation. The results are shown on the following graph:



The difference between the number of responses at 16 compared to at 9 and 12 evaluating the theories using the given evidence is significant ($p<0.09$).

At the end of the Balloons story, students were asked whether the theories about air rising and air expanding were different. Some students stated that they did not know whether the theories were different. Of the remaining responses, three types of argument were noted:

a) Limited conceptualisation of the theories

Some students did not seem to have differentiated the rising and expanding theories conceptually, as rising was interpreted as going upwards and then moving to fill available space:

I Exactly what are those ideas saying?

P That the hot air rises and makes it bigger and it expands. The air expands.

(Age 9)

b) Emphasis on the phenomenon

Some students stated that the two theories were the same because they both resulted in the balloon rising:

I Do you think there is any difference between those ideas or do you think they're the same?
P1 No.
P2 No, because they're both the same.
P1 Yeah, they're both the same. They both blow the balloon up.

(Age 9)

Such responses suggest that the theories and the evidence that they explain were not being differentiated by students, though it should be noted that this could be due to a limited conceptualisation of the theories by students.

c) Different conceptualisation by students

Some responses indicated that students conceptualised rising and expanding differently:

P Well the the balloon gets bigger when you heat it .. well because it it needs a lot of space to spread out in and er the tin isn't just big enough so ... like erm I've seen this programme before they put a match in a bottle then they put a balloon on the top and then it all blows up and then it bursts.
I Oh I see. Now do you think that that idea about it needing more space that you're explaining now is that the same thing as talking about hot air rising or is that a different idea? What do you think?
P Different.

(Age 9)

7.3 SUMMARY: FEATURES OF STUDENTS' REASONING ABOUT THE NATURE OF SCIENTIFIC KNOWLEDGE

- Students' conceptual background influences their reasoning about the nature of theories, evidence and experimentation. In particular, students' ability to articulate views of experimentation as hypothesis testing or empirical evaluation are constrained by their ability to make sense of the conceptual context (see 7.1.2d).

- In some cases, it appears that students do not differentiate theories and evidence, though this may be due to an inability to differentiate theories conceptually (see 7.2.3).
- Students draw upon empirical evidence in different ways to justify knowledge claims. In some cases, empirical evidence is not seen as relevant because the knowledge claim is ‘common knowledge’ (7.2.2a). In some cases students do not think that the aim of an activity is to explain a phenomenon by making a reliable knowledge claim, but rather to make the phenomenon happen (7.1.2a). Many students describe activities in terms of hypothesis testing with no reference to explanatory theory (7.1.2b). There is a trend with age for students to describe activities in terms of collecting evidence to evaluate a theory, where relevant, rather than in terms of a more mechanistic process (7.1.2d).
- The context in which students encounter activities and theories seems to influence how they are conceptualised. Many students will describe logically similar activities such as following a recipe to make a cake or a crystal as involving different processes, due to the context (7.1.2c).
- Students typically use a range of criteria on which to characterise experiments or theories, and these are often heavily grounded in the context. There is a trend with age to move from context-bound criteria to more abstract, generalisable criteria in defining these terms (7.1.2d).

8 DISCUSSION

Many of the above features of students’ characterisations of scientific knowledge have been noted in a number of different conceptual contexts on the Experiment probe, and on all three of the Theory Stories. They have also been noted on three further probes on which analysis has not been completed at the time of writing. Although we make no claim that these provide evidence of generalised reasoning skills among students in the 9 to 16 age range, it does seem likely that there are characteristic ways in which students may conceptualise investigative activities in school science lessons, and that these are different from the intended aims of the activities. In most cases, the range of characterisations within an age group was at least as great as the range between age groups, though some age-related trends have been noted. These age-related trends tend to be in the use of less context bound, more abstract reasoning such as thinking of the process of experimentation as involving collecting evidence in the context of an hypothesis, generalisation or theory, with an understanding that the evidence can then be used to evaluate the hypothesis, generalisation or theory.

We make no claim that our data show what children in the 9 to 16 age group *can* do. Rather, it shows what they *did* do in particular contexts which are related to the school science curriculum both in their conceptual content and in the ways in which theories and evidence are used to make knowledge claims.

The findings of this study can be used in curriculum design, and also to inform particular teaching approaches and interventions.

Curriculum design

A stated aim of science education involves engendering an understanding of the nature of scientific knowledge, and the history of science as an enterprise (e.g. AAAS, 1989; NCC, 1993). As curricula are designed to fulfil these aims, data from studies such as this one can be used to highlight some of the aspects that may need explicit attention, or be problematic to students. Age-related trends can be used to inform the sequencing of introduction of ideas and topics (Driver et al., forthcoming (b)).

Teaching interventions

The place of practical work is well established in the British science curriculum (Jenkins, 1979). This study suggests that the purposes for such work, as perceived by students, may for example involve making phenomena happen in ingenious ways, collecting and displaying data, or testing between discrete conditions, as opposed to empirical evaluation of generalisations, hypotheses or theories. Under these circumstances of mismatches in understanding the purposes of practical work between teachers and students, it seems questionable whether students' own empirical work is likely to promote conceptual change, as advocated in some science curricula (NCC, 1993). We make no claim that students in the 9 to 16 age range are not able to see the purposes of such work in terms of empirical evaluation, though this work may be useful in informing teachers of difficulties likely to be encountered by students, and areas that will need to be made explicit through classroom discourse.

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Liz Demsetz carried out many of the interviews for the study, and much of the coding. Her contribution to the quality of the data, her insights into finding meaningful ways to represent the data through analysis, and her ability to work to a demanding schedule are gratefully acknowledged. We also acknowledge helpful and challenging discussions with Dr. Nancy Brickhouse about the design of the study.

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APPENDIX 1: ASPECTS OF THE NATURE OF SCIENCE ADDRESSED IN THE STUDY

<u>Aspect of the Nature of Science, and component features</u>

1 **Purposes of Science**
The purposes of science in relation to the natural and social worlds.

2 **Nature of Scientific Knowledge**
The conjectural nature of theories, and the problematic application of theories to real world systems. Social, logical and empirical features in the evaluation and generation of theories.

3 **Science as a Social Enterprise**
The location of science in communities of people, the processes used within scientific communities to validate knowledge and the relationships between science and society.

APPENDIX 2: DESCRIPTION OF PROBES USED

Task Name, and Aspect	Focus of task	Description of task
Scientific Questions *Purposes of science*	Inferences are made about the role of empirical testing, and the boundaries of domains of scientific theories.	Pupils classify various questions on the basis of whether scientists might investigate the question or not. 30 pairs at ages 9, 12 and 16.
Experiment *Nature of scientific knowledge*	Inferences are made about pupil's understanding of the word 'experiment' and their ideas about the relationship between theory and evidence in experiments.	Pupils classify descriptions of people engaged in various activities as experiment', 'not experiment' or 'not sure', giving reasons. 30 pairs at ages 9, 12 and 16.
Belief *Nature of scientific knowledge*	Inferences are made about the warrants seen as necessary for belief by pupils, and the status of theories.	Pupils are asked for their warrants for belief for specified commonly accepted theories about the shape of the Earth and the flow of electric current. 30 pairs at ages 9, 12 and 16.
Theory Stories *Nature of scientific knowledge*	Inferences are made about children's ideas about the status of theories and their relationship with empirical evidence.	Pupils respond to three stories in which theories are described, and asked whether characters in the story know about the basis on which the theories are true. 30 pairs at ages 9, 12 and 16.
Real and Imaginary *Nature of scientific knowledge*	Inferences are made about pupils' ideas about the status of theories, and warrants for belief in theories.	Pupils respond to three cartoons in which contrasting opinions about the status of theories are raised. 30 pairs at ages 9, 12 and 16.

Theory & Evidence *Nature of scientific knowledge*	Inferences are made about the ability of pupils to differentiate theory from evidence, and the relationship between theory and evidence.	Pupils examine phenomena in the contexts of electricity and floating and sinking, and select theories to explain the phenomena. Empirical evidence is then presented for explanation using the theory. 30 pairs at ages 9, 12 and 16.
Plunger *Nature of scientific knowledge; purposes of science*	Inferences are made about the ways in which pupils conceptualise the processes involved in a school science activity.	Pupils watch a video of an investigation performed by 13 year old pupils in which they have to explain the phenomenon of a sink plunger 'sticking' to a surface. Pupils have to identify what they think the pupils are doing at each stage of the investigation,and why. 5 pairs of pupils at 9, 12 and 6.
Closure of Debates *Science as a social enterprise*	Inferences are made about the processes seen by pupils to influence the closure of a debate within the scientific community, and a debate on a scientific issue with broad social significance.	Pupils follow some teaching about the closure of debates within the scientific community, in the context of theories about Plate Tectonics and food irradiation. Views about the closure of debate are elicited prior to the teaching, during discussion and after teaching. 4 classes at age 16.

APPENDIX 3: ACTIVITIES PRESENTED FOR THE EXPERIMENT PROBE

Practical activity, outcome known Little suggestion of science in context	This person is making a cake, by following a recipe. They will measure out all the ingredients, mix them together, and bake the cake.
Practical activity, outcome known Stronger suggestion of science in context	This person is following some instructions, given on a worksheet by the teacher, to make some large crystals of salt.
Practical activity, outcome unknown Little suggestion of science in context	This person has just switched the radio on, but it did not work. They are now finding out why the radio won't work.
Practical activity, outcome unknown Stronger suggestion of science in context	This person is finding out which one of the three paper towels is best at mopping up water.
Measurement, no suggestion of underpinning theory	This person is a works at the post office. He is weighing parcels to decide which stamps the customer needs to buy.
Empirical evaluation of generalisation	This person has a hunch that there is usually more rain in April than in September. They are keeping a diary of the weather each day to see if their hunch is right.
Empirical evaluation of formally stated hypothesis	This person has an idea that the smaller the grains in sugar, the quicker it will dissolve in water, and is testing the idea.
Empirical evaluation of formally stated hypothesis	This person has an idea that electricity will go through <u>all</u> metals, but it only goes through a few things

	that are not metals. She is testing this idea.
Empirical evaluation of explanatory theory	When the bottle is heated the balloon fills with air. This could be because the air *expands* when heated, or because *hot air rises*. This person is heating the bottle upside down to find out which idea is the best.

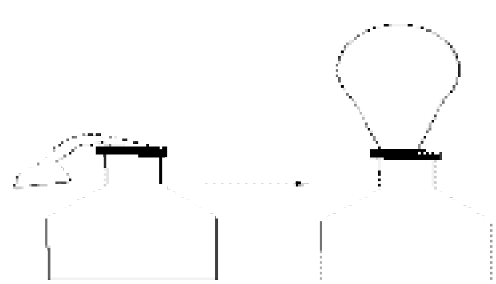
APPENDIX 4: THE 'THEORY STORIES'

Rusting

Tom and Brian were at the seaside, as part of their school trip. They were walking along the promenade, leaning on the railings and watching the seagulls swooping down to the sea in search of fish. Brian noticed that the railings were similar to some back at school.
'These railings are just like the ones at school, next to the main gate.'
'Not quite the same! The ones at school are nowhere near as rusty as these ones', replied Tom.
Sure enough, the railings at school were painted white, and looked quite shiny and well kept. These railings were also painted white, but the brown rust was breaking out through the paint all over the place.
'I have a theory about that..', said Brian
I *What do you think Brian means by 'a theory'?*
Have you any idea what his theory might be?
'Tell me then,' said Tom, 'what do you think is going on?'
'Well,' said Brian, 'it's to do with the sea. You know that the sea is salty?'
'Yes, go on..'
'Well, the saltiness of the sea is the answer!' said Brian.
'I can't see how that explains anything' said Tom. 'The salt's in the sea, and these railings are up here on the land. And anyway, how can salt make rust?'
'Well, you see,' explained Brian, 'salt helps all sorts of things to go rusty. My Mum says that when they salt the roads it makes the underneath of the car go rusty. And it's easy to see how salt from the sea gets up to the rails. When there's a storm the waves will splash water up here easily!'
'That's brilliant!' said Tom. 'That's it!'
I *Or is it? Can the two boys really be sure that Brian's theory is correct?*
What could they do to check if Brian's theory really was correct?

Balloons

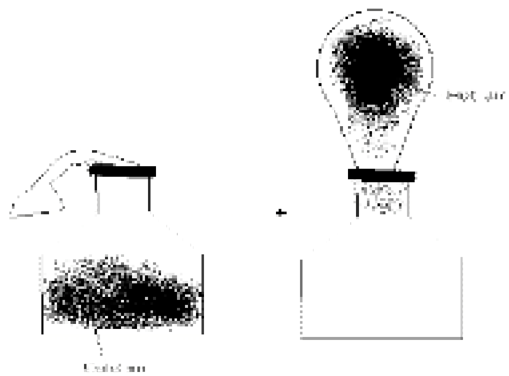
Kay and Sarah were working in the science class with a tin container with a balloon stretched over the neck, so that the air is trapped inside the tin and the balloon. Their teacher, Miss Stark, asked them to heat the tin gently and watch what happens. When they do it, they notice that the balloon gets bigger.



‘The balloon’s blowing up,’ said Kay. ‘Why’s it doing that?’
‘It’s the air,’ said Sarah. ‘The air’s going into the balloon’
‘How do you mean?’ asked Kay.
‘Well,’ said Sarah, ‘when it gets hot, more air goes into the balloon. Look, you can see it’s blowing the balloon up. There’s more air in it now.’
‘Yes,’ said Kay, but why does it do that?’
‘Well, I have a theory about that’, explained Sarah.

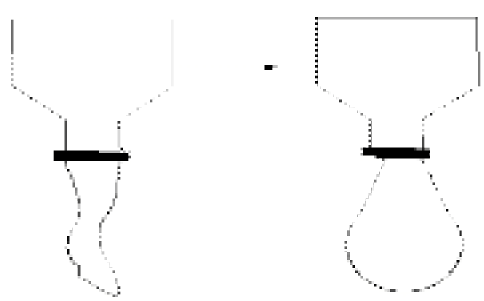
I *What do you think Sarah means by ‘a theory?’*
Have you any idea what her theory might be?

‘Go on then,’ replied Kay. ‘Tell me!’
‘Well, I think it’s because hot air rises. You know how you can feel hot air rising up from radiators and things. I think when we heat the tin the air inside gets hot and rises. So it goes into the balloon.’
Sarah then drew a picture to explain to Kay what she meant:



I *Can the two girls be absolutely certain that Sarah’s theory is right?*
What could they do to check if Sarah’s theory really was correct?

Kay thought about Sarah’s explanation for a minute. ‘I’m not so sure,’ she said. ‘What would happen if we held the tin upside down and then heated it? IF the hot air rises, it will just go into the top half of the tin, won’t it?’
‘OK, let’s try it,’ said Sarah. They let the tin cool down and then turned it sideways. When they heated it now, they found that the balloon got bigger.. just as it had done before.



I *Does this surprise you?*
What does this result tell the two girls?
Does this prove that Sarah's theory was wrong?

'I didn't think that would work,' said Sarah. 'I don't know what's happening to make it get bigger.'

They both thought for a minute. They Kay said, '<u>My</u> theory is that air expands when you heat it, so it needs more space, and that's why the balloon gets bigger'.

Sarah asked, 'What does 'expand' mean?'

'It means get bigger and take up more space', explained Kay.

I *The girls have now suggested two theories to explain why the balloon gets bigger when they heat the can:*
1 Hot air rises
2 When you heat air it expands
Do you think these theories are different?
Which of these theories is best at explaining the things they have observed?
Can they be absolutely certain that the better theory is right?
What could they do to check if the better theory really is correct?

<u>Germs</u>

Adam and Alice had been left to look after themselves over the weekend. It was the middle of summer, and their parents had gone away for a weekend. They had decided that Adam and Alice were old enough to look after themselves for a couple of days, but their grandparents had been told to keep an eye on them.

Adam was in the habit of staying up late on Saturday night, and getting up very late on Sunday morning. This weekend was no exception. When he got downstairs to make some coffee, he found to his horror that there was no milk in the fridge.

'ALICE! What have you done with the milk?'

'I might ask you the same thing. Did you have coffee last night after I went to bed?' she asked.

'Yes,' answered Adam. 'But there was plenty left. What have you done with it?'

'Nothing! But YOU left it by the sink, under the kitchen window. And it is now completely off! I had to do without milk this morning too.'

This was her moment of triumph - she had wanted to get one over on her brother like this for days. He quickly changed the subject, however.

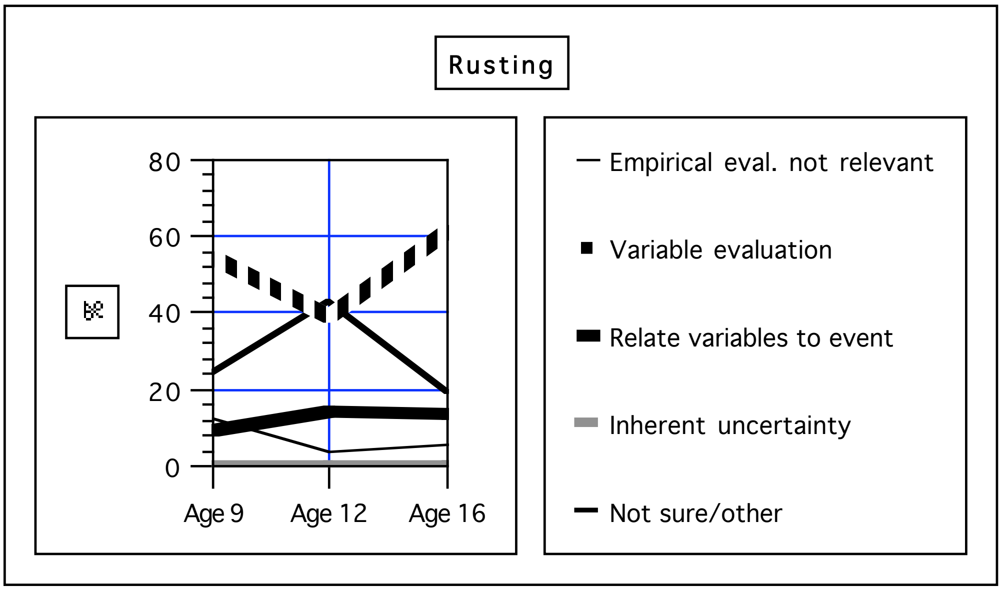
'I wonder why milk and other things go off quicker when they're not in the fridge?'

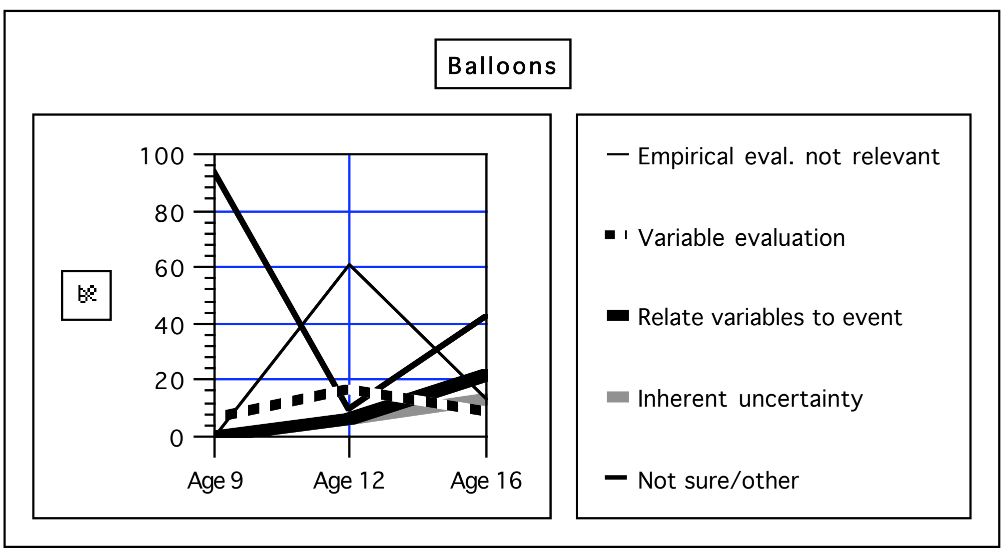
'I have a theory about that', answered Alice.

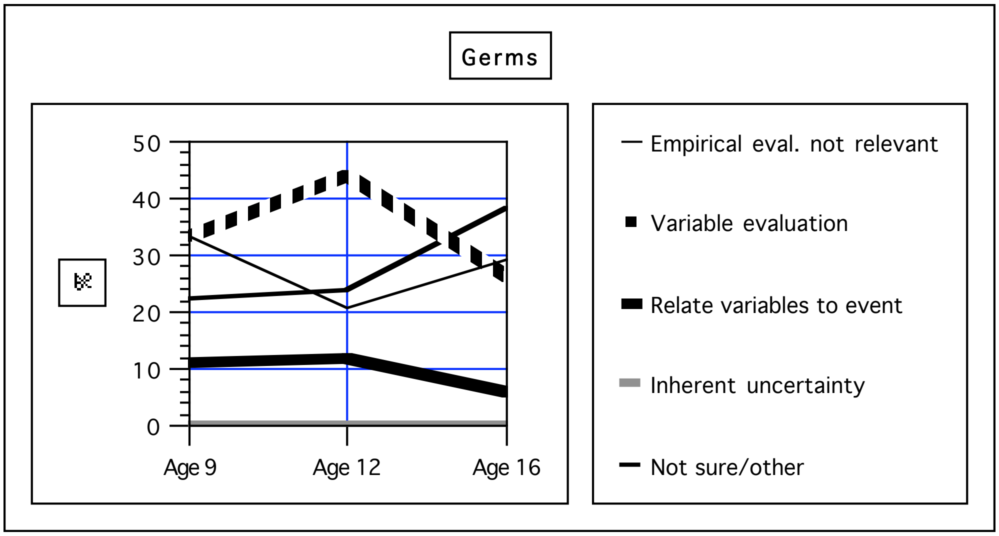
I *What do you think Alice means by 'a theory?'*
Have you any idea what her theory might be?

'Go on' said Adam, pleased that he had successfully changed the subject. 'What is your theory?'
'Well, germs make things go off, don't they? And germs can grow better in the warm than in the cold!'
'I see,' said Adam. 'That must be it!'
I *But can the they be absolutely certain that Alice's theory is right? What could they do to check if Sarah's theory really was correct?*

APPENDIX 5: RESULTS AT EACH AGE FOR TESTING THEORIES ON THE THEORY STORIES PROBE






Germs
%
50
40
30
20
10
0
Age 9
Age 12
Age 16
Empirical eval. not relevant
Variable evaluation
Relate variables to event
Inherent uncertainty
Not sure/other