

MAKING SENSE OF SCIENCE IN THE RECEPTION CLASS

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ABSTRACT

In the context of growing awareness of young children's capabilities, and debates about the nature of their reasoning in science, this study set out to explore the ways in which reception children make sense of classroom experiences in science. A particular challenge of the study was to develop appropriate and productive approaches to investigating young children's developing thinking.

The first phase of research, reported in this paper, concentrated on the topic of electricity. A series of case studies was undertaken to examine children's learning in a classroom context. Classroom sessions were video recorded and transcribed to examine the development of children's practical competence in circuit making, and interviews were carried out to elicit children's views about electric circuits.

Analysis of the classroom sessions revealed children's growing competence in circuit making through their self-directed efforts. The interviews prompted predictions and explanations that were not offered spontaneously. Responses indicated a range of models of the circuit and forms of explanation for what was happening in the circuit. The relationship between children's practical competence, predictions and explanations was not straightforward. Analysis revealed

marked differences in models of the circuit and forms of explanation in children with the same levels of practical competence. This has important implications for the ways in which children's views are assessed.

INTRODUCTION

Interest in science in the early years is growing. With the introduction of the National Curriculum in 1989 science became more fully established as part of the primary curriculum. More recently the Curriculum Guidance for the Foundation Stage (DFEE/QCA 2000) included science in the area of learning entitled Knowledge and Understanding of the World. The National Curriculum Level Descriptions and the Stepping Stones and Early Learning Goals associated with the Foundation Stage offer a basis for assessing young children's progress in science. However despite the apparent certainties of these frameworks they have been formulated in a period of considerable debate about the form and content of the science curriculum and the nature of young children's learning in science.

Research carried out over the last thirty years has provided an increasingly detailed picture of what it means to learn science. Extensive research into children's ideas indicates these are developed from a young age and may differ from scientific views. There is now considerable evidence about children's thinking in particular domains and the nature of the challenge that taking on scientific ideas may present. (See for example the research carried out by the *Children's Learning in Science* (for example Leach, Driver et al 1992) and *Science Processes and Concept Exploration* (for example Russell, Longden et al 1991) Projects in the UK or the *Learning in Science Project* (Osborne and Freyberg 1985) in New Zealand.) There is a growing body of work about the nature of scientific enquiry and what is involved in developing the

associated skills and understandings. Studies have explored strengths and weaknesses in children's scientific enquiries and children's views about their nature and purpose (Kuhn 1989, Foulds, Gott et al 1992, Millar, Lubben et al 1994, Driver, Leach et al 1994, Metz 1998). Features of progression in learning science are suggested and insights have been gained into the processes through which pupils may be introduced to scientific ideas and ways of working (Harlen 1992, Driver et al 1994). However there is much still to be learnt. Issues that have particularly influenced the development of this present study are highlighted here.

Further research is needed to examine the processes of conceptual change as they happen in everyday early years classrooms. While there is a growing body of work in cognitive psychology focusing on change processes (see for example Siegler 2000), most of this has been carried out with individuals in experimental settings. In science education detailed case studies of conceptual change have largely concentrated on junior or secondary age children (Scott 1992, Shephardson and Moje 1994 or Tytler 1994). Studies of conceptual change and of children's investigations highlight the interactions between children's conceptual and procedural understanding in learning (Schauble 1990, Kuhn, Schauble and Garcia Mila 1992, Millar et al 1994). The nature of these interactions, in particular the ways in which children use evidence from practical experience in developing their thinking, is an important area for further study in itself, This is of particular relevance given the considerable emphasis on children's own explorations and enquiries in current official guidance and policy on learning and teaching in science (DfEE 1999, QCA 2000).

Work in cognitive psychology using a wide range of techniques for assessing young children's capabilities is providing an increasingly positive picture of young children as active learners (Brown, Campione et al 1997). Application of these techniques to a study of learning in

classrooms could offer further insights into the ways in which children make sense of common school experiences. Studies based on more limited data are often only able to indicate what children can/cannot do or understand. Insufficient evidence is available to suggest *why* children think or act in particular ways that might provide useful implications for further support and teaching. Furthermore further development of techniques for assessment, sensitive to young children's learning in a classroom context would be of value both for research and classroom practice.

Finally growing attention is being given to the social context for learning in classrooms and the ways in which this may mirror processes within scientific communities (Brown and Campione 1994, Hodson 1998). While this was not a major focus for this study, further examination of the processes of learning in early years classrooms could provide further evidence of the ways in which interaction with peers and adults can support conceptual development.

The present study

This present study set out to examine young children's thinking in depth over a series of classroom sessions on electricity. It aimed to complement traditional psychological approaches that have tended to pay little attention to the educational context and to supplement research in science education, which has generally been carried out with older children. It sought to examine further two issues that have been the focus of growing interest in both cognitive psychology and science education; the processes of conceptual change and the interactions between children's explorations and their developing thinking in science, and to make a contribution to the body of existing research into the origins, status and nature of children's ideas.

Two phases of the study have been completed so far. The first phase of research, reported in this paper, consisted of a small number of case studies of children's learning in electricity. In the second phase a wider study will be undertaken of young children's thinking in electricity drawing on approaches developed in phase one. A final phase is planned to examine the impact of different kinds of experience on children's reasoning.

Research questions

The following broad research questions were used to guide the development of this first phase of the study.

1 ***How do children respond to classroom experiences in science?***

How do they interact with materials? What sorts of comments and observations do they make? What do they include in their recording? What do children consider they have learnt from their experiences?

2 ***What evidence is there of children's thinking about phenomena?***

What evidence of children's thinking is provided by their explorations, predictions and explanations? How are explorations, predictions and explanations related? What changes in thinking are observed over time?

3 ***What kinds of explanations do children offer?***

What is the range of views held by children about phenomena? What reasons do they give for their views?

METHODS

Context for the study

The research questions suggested some immediate implications for the conduct of the study. It would be necessary to work in a classroom context with young children undertaking everyday science activities and to consider children's responses over time and in detail in order to focus on learning processes. It was important to ensure that the topic selected and the activities observed would allow children to demonstrate the range of kinds of reasoning of interest. For example the activities employed by Kuhn (1989) in her studies of children's reasoning provided ample opportunities to examine children's abilities to identify causal *relationships* from successive observations. They gave less rich opportunities for examining children's thinking about causal *mechanisms* linked to underlying theories (Carey 1989, Samarapungavan 1992).

Taking these considerations into account, a reception class (of children aged 4 to 5 years old) was chosen as a context for the study. The class was in an inner-city school, which takes children from a wide range of ethnic, linguistic, and socio-economic backgrounds. Science-related activities took place in a regular basis. Electricity was the science topic in progress. Electricity is an area commonly tackled in early years settings. It offers rich opportunities for observation, investigation and questioning emphasised in early years science. Children are able to explore how devices work, try out what happens with different circuit arrangements and speculate about what is happening in a circuit.

Approach to data collection

It was recognised that a particular challenge of the study would be to develop appropriate

and productive approaches to investigating young children's developing thinking. Work with young children often reveals differences between responses given in different situations. Responses may vary depending on context or whether responses are child or adult initiated. (See for example Donaldson 1986 and Carey 1985). Reasoning shown in action may differ from views expressed in talking about experience or in responding to questions. This is examined for example in Piaget's detailed studies of the relationship between children's technical skill and their conscious knowledge and understanding in tackling a range of tasks (Piaget 1977 and 1978), and in Karmiloff – Smith's discussion of the transition from behavioural mastery to explicit knowledge in the process of development across a variety of domains (Karmiloff- Smith 1992). These studies indicate there may be a mismatch between what children understand or can do and what they are able to articulate. Furthermore Brown et al (1997) suggest that there may be a difference between what children choose to say or do and their capabilities. Children may only use their capabilities if prompted. Thus it is possible both to overestimate and to underestimate performance and understanding based on limited evidence.

Therefore I decided to undertake a small number of case studies of children's learning.

These were based on two main sources of data:

1. Children's responses to classroom activities in electricity

Children's responses were examined drawing on field notes made throughout each session; video recording of whole class discussions and of the activities of a focus group; the collection of documents such as children's work, teacher planning and flip chart notes made during class discussion and interviews with children in pairs using practical equipment and the video recordings as prompts for discussion.

2. Follow up interviews

To probe children's reasoning further follow up interviews were conducted in which children were shown examples of circuits and asked if they would work and why.

Sample

The whole class was observed and recorded during class discussion. During group activities the group making circuits was selected for observation. Others were involved in related or contrasting activities. The composition of the group varied over the session. Initially a number of children were allocated to the activity but during the afternoon children would join or leave the group in consultation with the class teacher. Children were selected for the interviews from those who had been observed. The selection included both boys and girls, reflected the differing backgrounds of children in the class and covered a range of attainment. In the material that follows pseudonyms are used throughout to protect the identity of the children.

CHILDREN'S RESPONSES TO CLASSROOM ACTIVITIES

Aims and content of the teaching sessions observed

Two sessions on electricity were observed. The teacher's planning gave information about learning objectives, the teaching sequence for each session and the practical resources made available to the children. These provided an important background to the analysis of children's responses to the electricity activities. Details are included in the table below.

Table 1: Aims and content of teaching sessions

<p>Aims for the sessions In discussion the teacher identified a number of key aims for the sessions. She hoped that the children would develop</p> <ol style="list-style-type: none"> 1. an awareness that a range of devices use electricity 2. a recognition of the need for two connections on the battery and on the device (The two connections on the battery and device provide a complete path round which electricity can flow.) 3. an awareness of the need for a complete circuit 4. knowledge of the effects of more batteries in a circuit 5. confidence in making circuits 6. confidence in tackling problems with circuits - what to do if they do not work. <p>It was anticipated that the experiences planned might also offer opportunities for discussion of children's models of electric circuits.</p>	
<p>Resources A range of resources was introduced deliberately from the start as follows: Bulbs and bulb holders, motors and buzzers, wires and crocodile clips, 1.5-volt batteries of different sizes and a range of switches.</p>	
<p>Teaching sequences</p>	
<p>Session 1 Discussion of children's ideas (15mins) <i>What is electricity? Where does it come from? What uses electricity?</i> Group activities (30 mins) <i>Drawing pictures of devices that use electricity in everyday life. Making circuits with a variety of components</i> Plenary (15mins) <i>Children sharing examples of circuits they made</i></p>	<p>Session 2 Discussion of findings about circuit making (15mins) Group activity (45mins) - making circuits Plenary (15mins) - sharing findings</p>

Data analysis

As a first step in processing the data, the material gathered was organised and recorded. A chart was drawn up of the data associated with each child in the class including the samples of recording collected, participation in the video recording of activities, contribution to class discussion and involvement in the interviews. Using the chart a sub-sample of three children was selected for whom a range of data was available, two girls and a boy covering a range of attainment. These three children were then tracked in detail through the sessions.

Video material was transcribed focusing on the aims of the sessions and the research questions. The activities and comments of each child over time were noted and recorded. Tape recordings of the interviews were also transcribed and key areas of discussion noted. The

children's actions and comments during the sessions were then reviewed alongside their contributions in the interviews and evidence of progress in relation to the teachers' learning objectives identified.

Results

Results are summarised briefly in Table 2. Actions and comments are listed in the order in which they occurred.

Table 2: Summary of children's responses in classroom sessions and initial interviews

Child	Main activities in classroom sessions	Kinds of comment made during activities	Incidents discussed in interviews
Fatima	Getting devices to work (bulb and motor) Seeking and giving help	Success/failure of circuits Asking for help Instructing others	Trying to make devices work Collecting components
Mercedes	Getting devices to work (bulb, buzzer, motor, switch) Showing others where to make connections Varying the number and type of battery Adding paper to the motor spindle	Success/failure of circuits Effects of more batteries Connections needed	Adding layers of paper to the motor spindle Replacing a broken light bulb
Hamsa	Getting devices to work (bulb, motor, buzzer) Helping others Varying the number of batteries in a circuit	Success/failure of circuits Connections needed Effects of more batteries	Adding 6 batteries to the circuit Power of the battery

The analysis of the video material gave some indication of the development of children's thinking in action. The actions of all three children suggested progress in relation to the aims for the sessions but they developed differing levels of competence in circuit making. For example at the start action and commentary were focused on success/failure and making something happen. Often the children adopted a trial and error approach. All three children were keen to get devices to work and drew attention to their achievements. However as sessions continued the approach of two of the children began to focus on the effects of changing the devices and batteries in a circuit.

Fatima showed increasing awareness of the different components needed, battery, device and wires, and her confidence in making circuits grew across the sessions as she made circuits more quickly and independently. However she retained a trial and error approach throughout. In her interview after the sessions Fatima's comments reflected her focus on getting devices to work and her awareness of the global features of a circuit such as the need for a battery and a device and connections between them, rather than the details of the connections needed.

'.. I was trying to get a light and a wire and it was not working ... I took one (battery) and another one.. took a wire.. and took some batteries.. and I hold it tightly and I put it in the battery and it was making a noise .. the one that turns around .. it looks like a alop..helicopter.'

(She is referring here to a motor with a piece of card attached to the spindle.)

Mercedes and **Hamsa** showed early success in making a bulb light. Over the course of the sessions they made a range of circuits using a variety of batteries and devices. They both spent time in each session watching and helping other children make circuits. Their comments as they explored progressed from global comments about circuits and components to a concentration on the *details* of connections needed.

There were times when their actions suggested they had developed a generalised idea of a circuit in terms of the connections needed on the battery and device and the importance of a complete circuit. For example they were able on a number of occasions to connect new devices very quickly and confidently and point out connections needed to others. When they applied their model of a circuit and were unsuccessful they proceeded to *check* components and connections rather than to *change* connections. When this failed they did not return to the trial and error approaches adopted earlier. For example Mercedes spent some time trying to get her

circuit with a switch to work (not realising what it was) and Hamsa struggled to make the buzzer sound (unaware that it was polarity sensitive and would therefore only work if connected one way round in the circuit). These two events provided the teacher with opportunities to discuss the nature and purpose of these particular devices.

Across the sessions both Mercedes and Hamsa investigated the effects of changing elements in the circuit. Mercedes varied the kind of device, the number and appearance of batteries and the layers of paper on the spindle of her motor. Hamsa added increasing numbers of batteries to his circuit.

In their interviews Mercedes and Hamsa focused on significant incidents that had occupied some time during the sessions.

Mercedes described her experiments adding paper to the motor spindle

'I put lots of paper on it (on the motor spindle).. it float round'

and an occasion when she discovered a light bulb needed replacing

' I tried it and it wasn't working. I put another one and it worked...the light bulb. There was something wrong with the light bulb'.

Hamsa's comments about the content of the sessions focused on his explorations with the motor and several batteries.

'I tried to make the round thing round and round and round – I got 6 batteries'.

"I did the crocodile clips and the round thing went round and round very fast'

He picked up on his comments about the 'power' of the battery and its transfer to the bulb.

'I tried to make it (the light bulb) work... I had to put some batteries on and crocodile clips and it worked.....The crocodile clips and the battery's got power and the light bulb has then'.

This suggests the beginnings of a concern to offer an explanation for what happens in a circuit

that goes beyond the mechanics of connections. His comment about ‘power’ from the battery being passed in some way to the bulb indicates an interest in underlying explanations and causal mechanisms.

Similar changes in action and reasoning over time are reported in the studies of Karmiloff - Smith and Inhelder (1974) and Metz (1991). As Brown et al (1997) suggest, these microgenetic studies show children shifting from *trying to succeed* to *trying to understand*, not just as they get older, but over time during activities. They offer a more positive view of young children’s capabilities (as theorists and epistemologists) than that given by ‘dipstick’ studies of children’s views at particular points in time.

FOLLOW UP INTERVIEWS

Design of the interviews

The follow up interviews were designed to probe further children’s ideas about electric circuits. One possible approach to the interviews was suggested by a number of previous studies that have attempted to explore the models or rules that children use in responding to questions or in solving problems in particular domains. (See for example Siegler’s rule assessment method devised to explore the rules children used in tackling balance scale problems (Klahr and Siegler 1987), Whitelock’s investigation of a common-sense model for thinking about the causes of motion (Whitelock 1991) or Vosniadou and Brewer’s exploration of children’s mental models of the earth (Vosniadou and Brewer 1992)). In each of these studies a series of problems or questions was developed to explore key features of children’s understanding. Previous research and exploratory studies were then used to propose rules or models that the children might be

using in addressing these questions, and children's responses predicted according to each rule or model. Children's actual responses were compared with those predicted to see how far the variation in children's responses could be explained by assuming consistent use of the rules or models proposed. In this way it was possible to explore the models or rules that might underlie children's reasoning or actions without probing these directly. In a similar way it might be possible to pose a series of questions about electric circuits to probe children's models of the circuit. If this approach could be combined with discussion about children's explanations for their views and opportunities for practical demonstration of circuit knowledge, it would be possible to explore and compare children's reasoning shown in action with more explicit reasoning revealed in responding to questioning or in offering explanations.

The network provided by Osborne, Black et al (1991) offered the following range of practical models the children might use in responding to circuit examples

No response

A single connection only to the battery/device

2 connections (incorrect) – 2 battery connections, 1 device connection

2 connections (incorrect) – 2 battery connections, 2 device connections (incorrect)

2 connections (correct) to both battery and device.

The interviews used three sets of 8 photographs of circuits that would, or would not work, designed to focus on key features of the circuit and to discriminate between the models. The characteristics of the circuits chosen are indicated in Table 3 below.

Table 3 Circuit examples chosen for the interviews

1	One wire only – incomplete circuit	1 connection on the battery 1 connection on the device
2	Two wires – gap in the circuit	1 connection on the battery 2 connections on the device
3	Two wires – gap in the circuit	2 connections on the battery 1 connection on the device
4	Two wires – complete circuit but one connection only on the battery	1 connection on the battery 2 connections on the device
5	Two wires – complete circuit but one connection only on the device	2 connections on the battery 1 connection on the device
6	Two wires – complete circuit, two connections on the device but incorrect	2 connections on the battery 2 connections on the device but incorrect
7	Two wires – complete circuit, correct connections	2 correct connections on the battery and on the device
8	One wire only – complete circuit, correct connections	2 connections on the battery 2 connections on the device

Individual interviews were tape-recorded. Children’s predictions and any comments made were recorded on a prepared chart and the order of the presentation of cards noted. Field notes were made providing further details of the children’s reactions that might not be picked up on the tape recorder; - in particular, details of any circuits made in the final part of the interview. As indicated above the eight children selected for interview had all appeared in sections of video footage of the classroom sessions. The sample contained both boys and girls, covered a range of attainment and included children from a variety of ethnic backgrounds. The three children studied in detail following the classroom observations were part of the sample. The interviews took place six months after the classroom observations. By this time the children were in a year 1 class. They had received no further teaching in school on electricity.

Analysis of the interviews

As a first step in the analysis charts were constructed to summarise the predictions made by each child for each circuit example. This made it possible to examine patterns and consistency in predictions across examples, differences between children and the particular challenges

provided by individual circuit examples. To examine the practical models of the circuit used either implicitly or explicitly in making responses, children’s predictions were compared with those consistent with the models of the circuit provided by Osborne et al (1991).

The different explanations given by children for their predictions were listed and similar explanations grouped according to the following broad categories shown in Table 4.

Table 4: Explanation types and categories

Category	Explanation types	Examples
<i>Components</i>	<ul style="list-style-type: none"> • Needs a new battery • Needs a new bulb • Needs another wire/needs two wires 	‘need a new battery’ ‘need another wire’
<i>Connections</i>	<ul style="list-style-type: none"> • Gap/not attached/not joined/touching • Move connection/wrong connections • Connections missing/need two connections 	‘need to join it’, ‘that should be there’ ‘need two (connections)’
<i>‘power from the battery’</i>	<ul style="list-style-type: none"> • No power • Not so much power • Is giving power 	‘battery’s got power’ ‘has got no power from the battery’
<i>Path for electricity</i>	<ul style="list-style-type: none"> • Power cannot go that way • Metal not touching or Plastic/glass blocks 	‘metal has to be touching round’ ‘power can’t go that way – no way getting to the light bulb that way’
<i>Additional categories</i>	Other and no reason	

As a final stage in the analysis, findings from the interviews were considered alongside those drawn from classroom observations. Children’s performance and reasoning in the different contexts was compared.

Results

A summary of results is given in Table 5 below. The table gives an indication of the children’s practical competence, the model of the circuit that best matched the children’s responses and the types of explanation they offered for their predictions.

Table 5: Comparison of practical competence, models of the circuit and forms of explanation

Child	Practical competence	Practical model (s) consistent with predictions	Type(s) of explanation
Fatima	Aware of the need for a connection between battery and device- but needed help to make devices work	1 connection	Components
Junior	Aware of the need for a connection between battery and device- but needed help to make devices work	1 connection	Components
Syreeta	Able to make circuits with a bulb, battery and wires.	1 connection/ beginnings of 2 connections	Components Connections
Kenneth	Able to make circuits with a variety of devices and with several batteries.	2 connections (incorrect) wrong connections on device	Components, Connections, Power from the battery Path of conducting material
Hamsa	Able to make circuits with a variety of devices and with several batteries.	2 connections (correct)	Components, Connections
Mercedes	Able to make circuits with a variety of devices and with several batteries.	2 connections (correct)	Components connections
Yaseen	Able to make circuits with a variety of devices and with several batteries.	2 connections (correct)	Components connections
Jack	Able to make circuits with a variety of devices and with several batteries.	2 connections (correct)	Power from the battery Path of conducting material

For **Fatima and Junior** their predictions and explanations mirrored their practical competence.

Although Fatima and Junior were beginning to explore connections needed in the classroom sessions, comments remained at a global level focusing on the components required. At the end of the interview neither child was able to make circuits successfully without assistance. Fatima initially tried putting the bulb holder on the top of the battery and then said '*you need a crocodile clip too and put it on the battery*'. Junior loosely linked the battery and bulb with a wire. Fatima's and Junior's attempts to make the bulb light suggest they thought that only one link was required between the battery and device. The responses of Fatima and Junior were all consistent with the 1 connection model of the circuit.

The remaining six children were all able to make circuits competently and confidently both in the classroom and in the interview but showed differing patterns of prediction and kinds of explanation.

Syeeta showed competence in making circuits both in the classroom and in the interview. However she did not articulate fully the connections needed, so her practical competence was not reflected in her predictions and explanations, which focused mainly on components. In contrast to her practical competence, most of Syreeta's responses in the interview were consistent with a 1 connection model of the circuit. However during the course of the interview she began to articulate an awareness of the need for two connections on the device. In relation to example 5 (one connection only on the device) she commented that the connections '*needed to be moved*'. This development was reinforced during the final part of the interview. She made a circuit by herself and noticed that if you remove one connection from the device it did not work. She said with emphasis '*if you take that one (connection) away and leave that one by itself it won't work*'.

Kenneth's classroom competence was reflected in his performance in the interview. He talked explicitly about the working components required to make a circuit, the need for a complete circuit with no gaps and the need for two connections on the battery or device. He was able to articulate the correct connections needed for example '*the wire needs to be on that side of the bulb and that side of the battery*.' The interview also revealed aspects of his thinking not shown in the classroom setting – his awareness of the need for metal connections and his developing thinking about how the 'power' in the battery might be transferred to the device. He commented '*the metal has to be touching round*', pointing round the circuit and '*needs to be power in the battery*'. This suggests the beginnings of thinking about explanatory mechanisms. Kenneth was aware of the need for two connections on the battery and device but did not focus on the specific connecting points on the device. Apart from the prediction for example 8 (the complete circuit with one wire) his responses were consistent with the model of the circuit 2

connections (incorrect) – incorrect connecting points on the device.

The predictions and explanations of **Hamsa, Mercedes and Yaseen** showed explicit awareness of connections that they had also articulated and demonstrated to peers and their teacher in the classroom. For example Mercedes said ‘*not attached, there’s a gap*’. Yaseen commented ‘*if you put that clip over there it will work*’ and Hamsa ‘*No there should be two (connections) .. that should go on there*’. In the classroom and in the final part of the interview, Hamsa also showed interest in the power of the battery and the effects of adding more batteries in a circuit. All three children gave responses consistent with the category 2 connections (correct) except in the case of circuit 8 (the circuit with one wire).

Jack’s predictions reflected his practical competence in making circuits. What was particularly striking in his case was the way in which the interview provided a context to explore his explanations for what is happening in a circuit. His explanations concentrated on the route for ‘electricity’ from the battery. His comments suggested he was aware a *path of conducting material* was needed for a circuit to work. For example he said, ‘*the power can’t come out of the battery there – you’re not supposed to see electricity*’ or ‘*power can’t get that way*’ (gaps in the circuits) or ‘*no, can’t go through that – it’s blocked*’ (connections made to plastic/glass). In the three circuits with a gap (1,2 and 3), he reasoned that there would not be enough ‘power’ to light the bulb, for example, ‘*not so much power – can’t come out of the battery there*’ or ‘*not so much power so the bulb won’t shine so bright.*’ His comments and actions suggested a model of the circuit in which electricity* flows out from both ends of the battery to the device. Electricity could flow in one direction through one wire to the bulb but this would not be sufficient to make it light. Flow through two wires was needed from both ends of the battery to make the bulb light. In examples 4 and 5 (one connection only on the battery/device) he demonstrated explicit

awareness of the need for two separate connections to the battery and the device, again talking about a route for electricity '*power needs to go round there*' (on the battery) and '*power can't get in on the other side*' (on bulb). These explanations went beyond practical theories in offering an explanatory model for what was happening in a circuit.

Jack's model was applied consistently and consciously across the interview but it also generated some doubt in his mind. He was not entirely sure about example 4 where there were two wires from the battery to the device and example 8, the complete circuit with one wire. Jack's awareness of his own thinking processes was further underlined in the final part of the interview. When asked what he would like to show or explore further he quickly selected the two cards he was not sure about and made the circuits. In finding the complete circuit with one wire did work he said '*not that light – put more batteries to get it lighter*'. This comment was consistent with the model of the circuit he had developed. Jack's predictions were consistent with the category of two connections (correct) apart from example 8 (the complete circuit with one wire).

(* In primary schools the general term electricity is commonly used to cover both electrical energy and electrical charge. Distinctions between these terms are difficult at this level.)

Consistency in response

Overall children's predictions were fairly consistent. 54 of the 64 possible responses (eight children x eight circuits) were consistent. There were ten instances of a change in response. Seven of the ten changes were in a positive direction, which may indicate learning through the interview procedure itself. In particular being presented with a range of examples may help focus attention on key features of the circuit. The circuit that caused uncertainty for the children who otherwise predicted correctly was circuit 8 (the complete circuit made with one

wire). While they were able to demonstrate the connections required on the battery or device, they were unsure whether two wires were needed. The circuit with one wire was not an arrangement they had experienced in the classroom.

Nature of children’s explanations

The differing categories of explanation offered show similarities to the forms of explanation discussed by Metz (1991) in her discussion of children’s developing explanations for moving gears. She identified three phases in the development of explanations

- Phase I Function of the object as explanation - in which an object is an explanation for the event e.g. the knob on the gear
- Phase II Connections as explanation - in which connections amongst the gears provide the basis for explanation
- Phase III mechanistic explanations - when an account is provided of *how* movement is transmitted

Using this framework the children’s explanations could be characterised as shown in Table 6.

Table 6: The nature of children’s explanations

Children	Categories of explanation used	Link to Metz forms of explanation
Fatima and Junior	Components	object as explanation
Syreeta	Components, connections	Object as explanation Connections as explanation
Hamsa, Mercedes & Yaseen	Connections	Connections as explanation
Kenneth	Components, connections, power from the battery, path of conducting material	Object as explanation Connections as explanation Beginnings of mechanistic explanation
Jack	Power from the battery, path of conducting material	Mechanistic explanation

Metz proposed that the increased and detailed focus on connections in Phase II provided the basis for the mechanistic explanations characteristic of phase III. There were some suggestions of this transition in the analysis of classroom observations discussed earlier. In the interviews

too, greater competence in circuit making was associated with growing awareness of connections needed and increasing speculation about how ‘power’ from the battery might be transferred to the device. (This is also reported by Shephardson et al (1994) in their detailed study of children’s understanding of electric circuits.) However developing mechanistic explanations for electric circuits presents a different kind of challenge. Mechanistic explanations for moving gears can be developed through direct observation. In contrast mechanistic explanations for what is happening in a circuit involve entities and processes that cannot be observed directly.

In examining the differing nature of children’s reasoning useful parallels can also be drawn with the framework developed by Driver et al (1996) in their study of young people’s images of science. They identified three kinds of reasoning:

Phenomenon-based reasoning in which there is no clear separation between the description of the phenomenon and the explanation. The purpose of practical investigations is to find out how the world works.

Relation-based reasoning - in which distinctions between description and explanation are beginning to be recognised. Enquiries involve investigation of relationships between variables.

Model-based reasoning - in which a clear distinction is appreciated between description and explanation. Explanation may involve the use of theories and models that go beyond the experimental data.

For some children (e.g. Fatima and Junior) explanations did not go beyond a description of components. For others (e.g. Hamsa, Mercedes and Yaseen) their practical models of the circuit and their explanations were the same, focusing on generalisations that could be made from direct observation. The responses of Kenneth and Jack suggest they were beginning to offer explanations that go beyond what is directly observable in considering explicitly the flow of

‘electricity’ in a circuit.

Their views show some similarities to the models of the behaviour of electricity found by Asoko (1996) in her study of 8-9 year old children.

Table 7: Predominant models of the behaviour of electricity (Asoko 1996)

<i>No model evident</i>
<i>Source to consumer</i> (something travelling from the battery to the bulb - often energy but in some cases just a generalised notion of electricity)
<i>Both wires carry something to the bulb</i> (energy, power or electricity)
<i>Circular flow of something</i> (energy or electricity)
<i>Circular flow of current</i>

Jack’s explanations indicated he considered *both wires carry something to the bulb*. Kenneth’s comments and actions suggested *circular flow of something* round the circuit. The interview did not set out deliberately to probe children’s models of the behaviour of electricity so it is only possible to make very limited comments on the views of the other children. The explanations given by Fatima, Junior and Syreeta were consistent with a *source to consumer* model. The explanations offered by Hamsa, Mercedes and Yaseen could be consistent *with both wires carry something to the bulb* or a *circular flow of something* round the circuit.

Finally, as indicated in the summary of the interviews above, 6 of the children (Fatima, Syreeta, Kenneth, Hamsa, Jack and Mercedes) commented explicitly on the effects of more batteries in a circuit. They recognised more batteries would make the light brighter. In addition Kenneth and Hamsa commented that when you use several batteries you need to have the batteries the right way round.

Summary and conclusions

The analysis of the video transcriptions revealed children’s growing confidence and competence in circuit making through their self-directed efforts. Children showed an ability to take account

of both positive and negative evidence in developing their ideas about circuits. A variety of approaches to enquiry were shown, from the trial and error approaches adopted by children in establishing the connections needed in a circuit to the more systematic investigations undertaken later in the sessions by those competent in circuit making. Children's perspectives gained from the group interviews confirmed this picture. Their comments reflected the forms of activity and competence seen in the classroom. These findings are in accord with the positive aspects of children's enquiries reviewed by Metz (1998).

The individual interviews were successful in engaging children and prompting predictions and explanations not offered spontaneously. Children's predictions corresponded to a range of models of the circuit as suggested by Osborne et al (1991). Responses to the circuit examples were mostly consistent. Where children changed their predictions further examination of their explanations suggested this might have been a product of settling into the interview or of transitions in thinking as a result of the interview process itself. There was no particular evidence of an arbitrary response. In terms of the explanations offered, these were different in kind. Explanations focusing on components showed features of primitive agency reasoning in which an event can be explained as a function of the object itself. Explanations that referred to connections concentrated on the physical arrangement of the circuit as a basis of explanation. Within this category differences were evident between explanations that referred to connections in *general* terms and those identifying the *specific* details of connections needed. Finally there were children who offered explanations referring to the path for electricity or the power of the battery. This group of explanations went beyond generalisations that could be made from direct observation to a consideration of mechanisms that are not directly observable. These different types of explanation show some similarities to different forms of reasoning proposed by Driver

et al (1996) in their study of children's ideas about the nature of science. Studies carried out by Shepherdson and Moje (1994), Asoko (1996) and Gutwill et al (1996) report similar kinds of explanations offered by older children and inexperienced adults. A more detailed consideration of the children's ideas in electricity in the light of previous research in the field will follow in a forthcoming paper.

The study provided an opportunity to explore the relationship between children's practical competence, predictions and explanations. Findings suggest the relationship is not straightforward. Greater practical competence often preceded the identification and articulation of the connections needed in a circuit. Therefore children with the same levels of practical competence made predictions characteristic of different models of the circuit, or gave different explanations for what is happening in a circuit. Furthermore children who made the same predictions also offered different types of explanation for their views. This gap between knowledge shown in action, predictions and explanations is widely discussed (Piaget 1977, 1978, Karmiloff-Smith 1974, 1986) and has important implications for the ways children's views are assessed.

The approaches to data collection employed in the study offered opportunities to examine children's responses over time and in detail. Children engaged enthusiastically in both classroom sessions and interviews and sought actively to make sense of their experiences. Comments during classroom sessions and in the interviews indicated that some children were seeking not just to make circuits work but to understand and explain how they worked. There were indications of the ways in which interaction with peers and adults may have supported children's learning. In the classroom sessions there were frequent examples of children watching and helping each other make circuits. Although they were generally very engaged in practical activity

and talk was limited, there were times when children made comments to the audience of their peers and teacher about their observations and progress. The interview procedure encouraged children to express their views and there was some suggestion that it may have prompted changes in thinking and further explorations. As discussed by Wegerif and Mercer (1997), in both situations thinking was articulated in the context of communication with others. Learning through the interview procedure was explored further in the next phase of the study.

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