MAKING SENSE OF SECONDARY SCIENCE

Research into children's ideas

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ELECTRICITY

MAKING A COMPLETE CLOSED CIRCUIT

Most pupils' introduction to learning about electricity the world over involves using a battery, wire, and a 1.25V bulb to make the bulb light. Pupils generally tackle this with enthusiasm and also with certain established ideas about how batteries and bulbs work. Several researchers[1] [2] [3] [4] [5] have investigated pupils' earliest ideas about electricity and they report that these ideas generally indicate a source–consumer model in which the battery gives something to the bulb. In practice this model underlies the common examples of circuits which are built by children in the 8–12 age range in their initial attempts to light a bulb. Common arrangements of a battery and a bulb, identified by Shipstone, are shown in Figure 15.1.

It seems that many strategies designed to help pupils to understand electricity actually introduce and reinforce problems.

PUPILS' IDEAS ABOUT A SIMPLE CIRCUIT

Solomon *et al.*[6] and Licht[7] have pointed to the importance of pupils' background awareness of, and interest in, electricity. Licht found, among 207 pupils studied, that danger/safety, sound and video apparatus and electronics were the contexts in which pupils were most interested. This of course leaves the teacher with the difficult task of maintaining pupils' interest in the modest DC circuits which will help them to begin to understand the phenomena.

Pupils' mental models of a DC circuit

The models which are used by children to explain the phenomenon of a simple circuit have been studied in several countries: New Zealand, Australia, the USA, Sweden, Greece, France, and Germany as well as the UK. Osborne and Freyberg's work in New Zealand[8] identified four

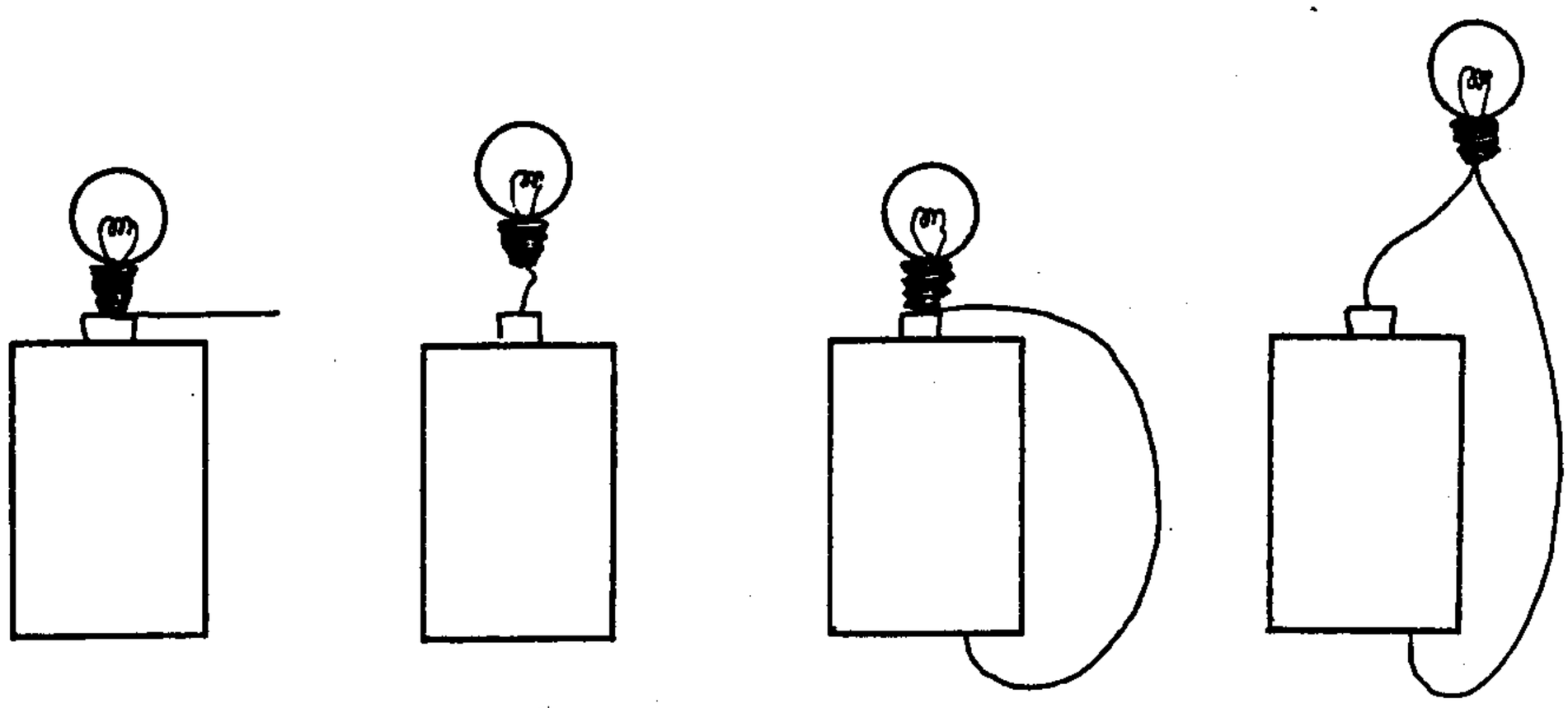

Figure 15.1 Examples of attempts to light a bulb
Source: D. Shipstone, 'Electricity in simple circuits', pp. 33–51 in R. Driver, E. Guesne and A. Tiberghien (eds), *Children's Ideas in Science*, Open University Press, Milton Keynes, 1985.

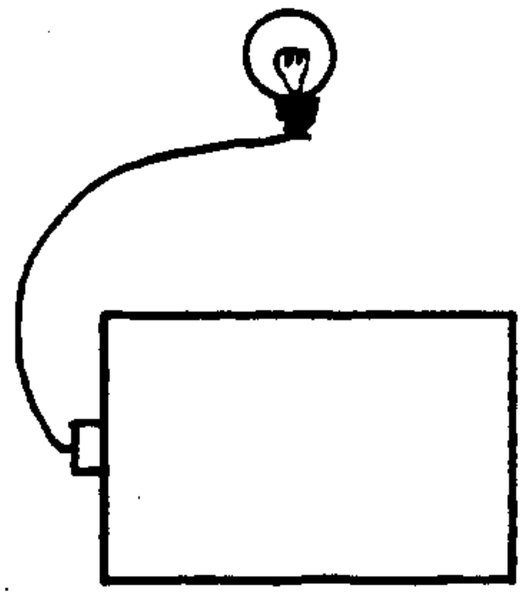

Figure 15.2 The unipolar model (A)

explanatory models (see Figures 15.2–15.5) which have since been found by other researchers world-wide.[2 5 9 10 11] Some of these alternative models are very firmly held, not only by young pupils but by physics and engineering students who are regularly involved in practical work and calculations relating to circuits.

The first of these models is illustrated in Figure 15.2. Here, pupils regard only one wire as active and, whilst most come to recognise the practical requirement for a complete circuit, they nevertheless think that the second wire doesn't play an active part. It is sometimes regarded as a safety wire.

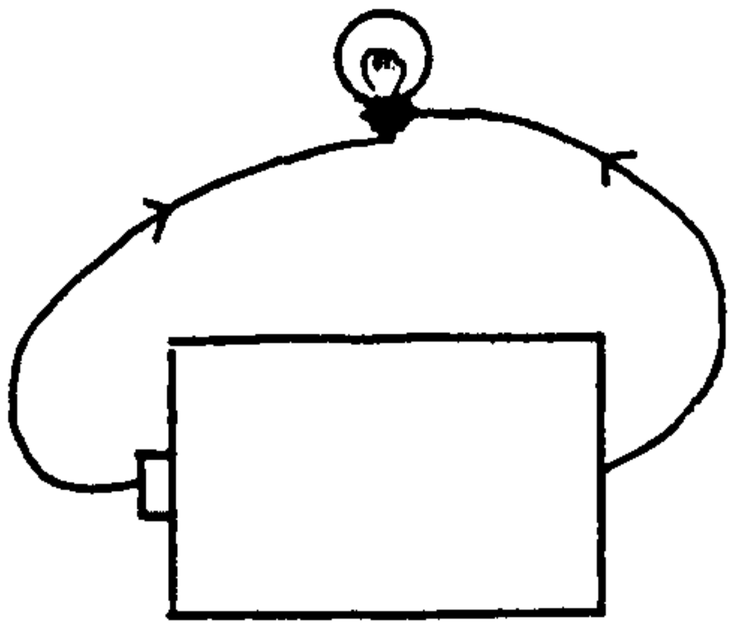

Figure 15.3 The clashing currents model (B)

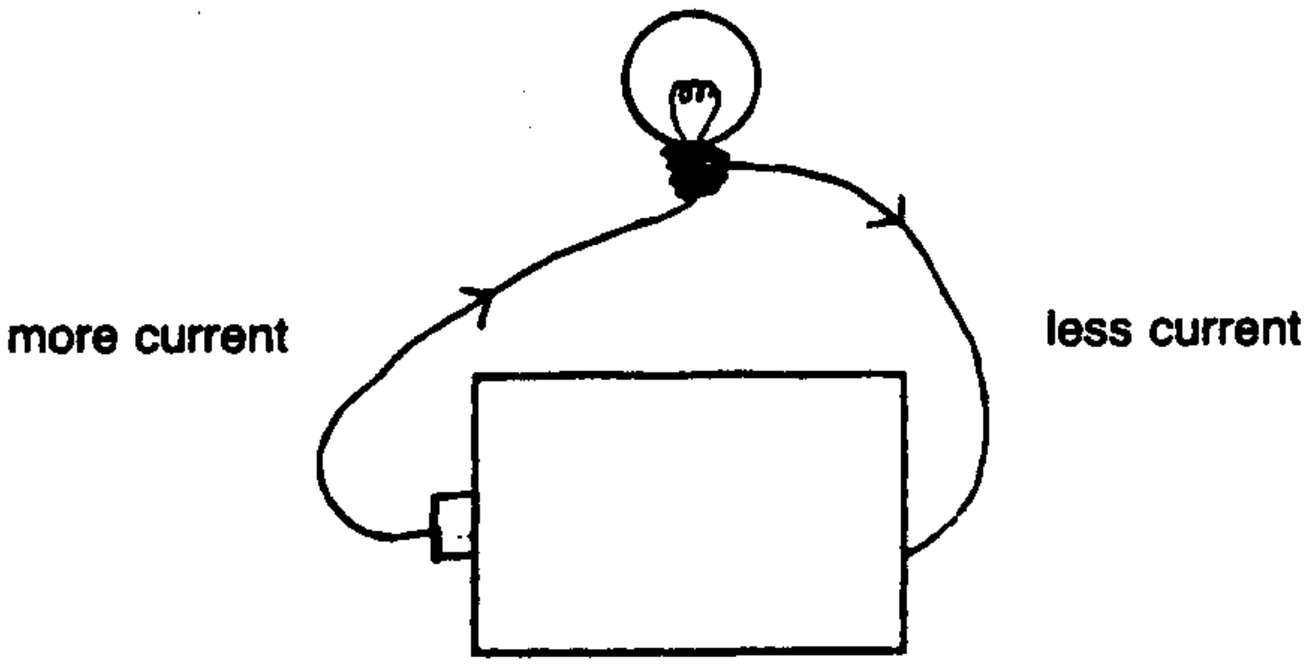

Figure 15.4 The current consumed model (C)

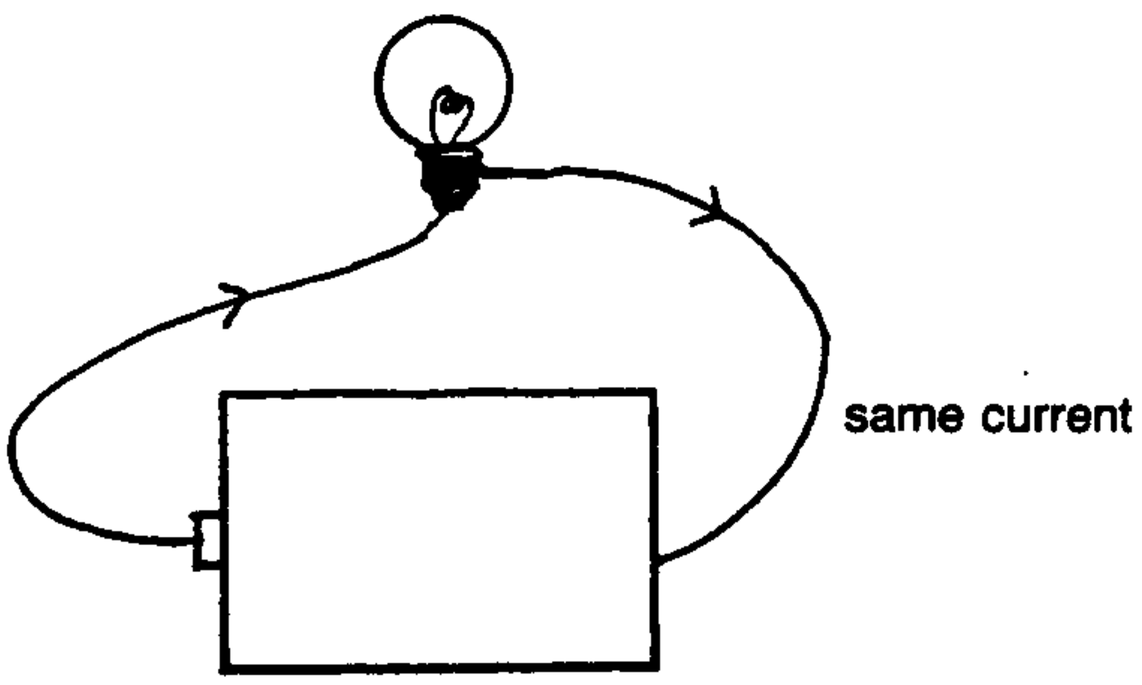

Figure 15.5 The scientists' model with current conserved (D)

A second model is shown in Figure 15.3. Pupils think of current flowing from both terminals of the battery to the bulb. They sometimes explain the light in terms of the 'clash' of the two currents.

In the third model (Figure 15.4) current is seen as 'used up' by the bulb and so there is less in the wire 'going back' to the battery. Some pupils expect a second bulb to be less bright than the first when two bulbs are in the circuit: others imagine components sharing the current equally but in either case current is 'used up' by the bulbs.

The fourth model (Figure 15.5) shows the magnitude or value of the current unchanged in the return wire.

It is notable that all the prevalent alternative models are 'sequential' models in which something from the battery travels around the circuit, meeting wires and components in sequence. This deep-seated notion, with its roots in the 'cause and effect' everyday experiences of other phenomena, underlies many of the problems which pupils have in understanding the behaviour of electrical circuits. It is this notion which might be considered as the underlying mental model having various expressions.

Popularity of models A, B, C and D with different age-groups

The four models (A, B, C and D) appear to vary in popularity with different age-groups. Usually less than 5 per cent of secondary pupils use the unipolar model A. Osborne and Freyberg[8] found model B thinking in the explanations of less than 10 per cent of 15-year-olds, whilst it was held by nearly 40 per cent of 12-year-olds.

Shipstone found that almost 50 per cent of 12-year-olds in an 11–18 British comprehensive school held a 'current-used-up' model, C. This rose to 60 per cent in 14-year-olds and fell to less than 40 per cent in 17-year-olds. (All the students tested had studied electricity in the year in which they were tested and the sixth-formers had completed 'A' level work.) The scientific model D was held by less than 10 per cent of 12-year-olds and less than 40 per cent of 15-year-olds, only rising to 60 per cent in the 17-year-olds (Figure 15.6).

Gott[5] found that 50 per cent of 15-year-olds had a 'current-used-up'

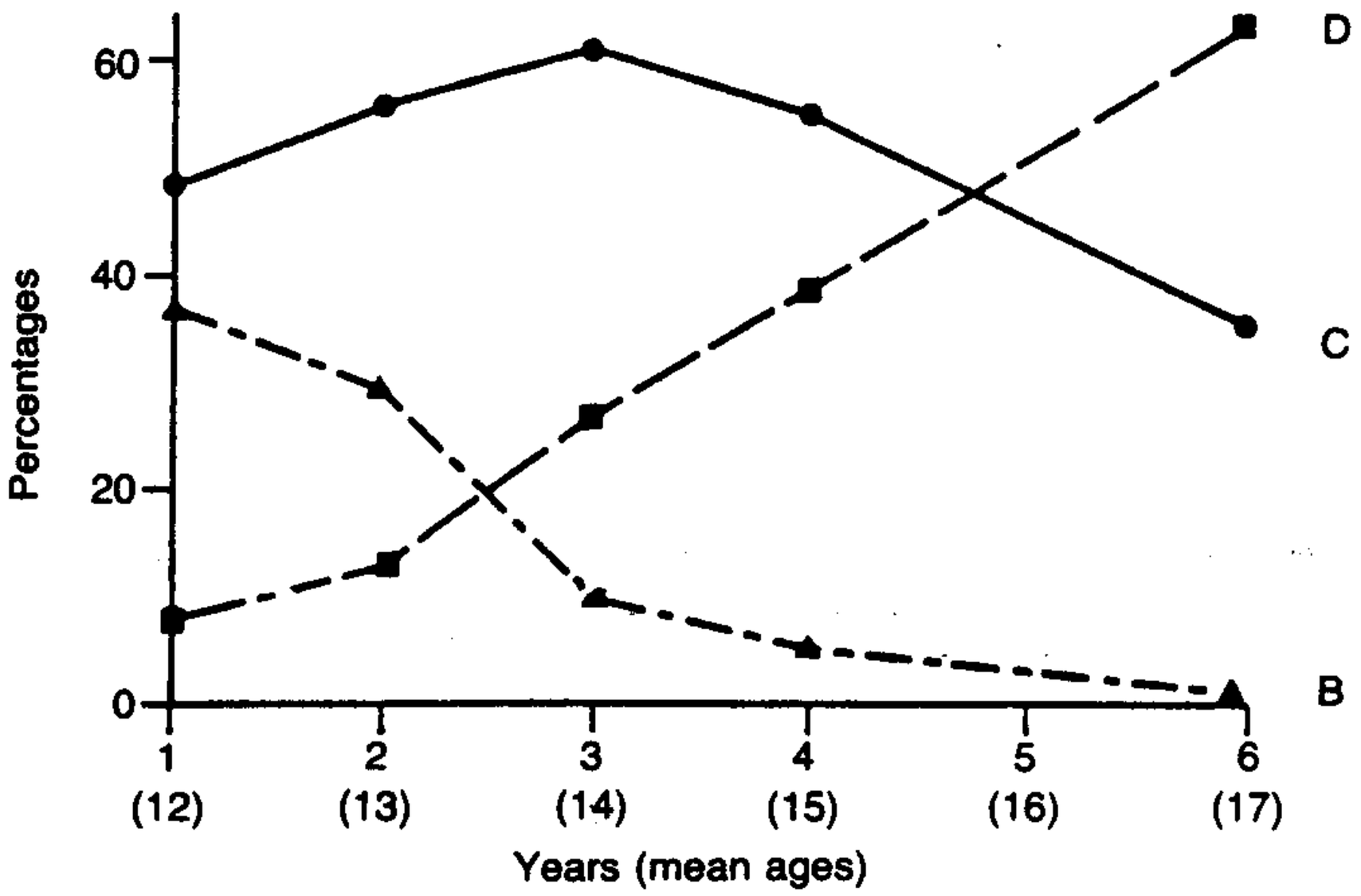

Figure 15.6 Popularity of models B, C and D

Source: D. Shipstone, 'Electricity in simple circuits', pp. 33–51 in R. Driver, E. Guesne and A. Tiberghien (eds), *Children's Ideas in Science*, Open University Press, Milton Keynes, 1985.

model and it appeared that having two bulbs in a circuit reduced the number of pupils conserving current.

Osborne and Freyberg[8] have found the use of two ammeters in a circuit, and also the analogy of the heart and blood circulation, to be effective in moving some pupils' thinking to model D. However, Gauld[12] has shown that pupils tend to hold on to their consumption model, C, even 'remembering' ammeter readings to support that view. Dupin and Johsua[11] have found that pupils try to account for equal ammeter readings on either side of a bulb in terms other than current conservation.

The point of particular concern is that pupils need to be using the model D explanation of a circuit before they can hold the scientifically accepted view of ammeters, voltmeters, potential difference, resistance or series and parallel circuits. Notably Osborne[13] found that, in a small group of 11-year-olds, 86 per cent held model D after a critical lesson in which current measurements were made on either side of a bulb but that only 47 per cent still held it after one year.

Closset[14 15] suggests that it is important to teach pupils what a model is and that any model has limited use. Most of the researchers recognise the value of presenting pupils with a cognitive conflict in which experiences challenge their existing models. However, the point is made that this in itself is not enough – that it is necessary to offer, at the same time, a new model which impresses the learner as having an advantage over the one they hold. Closset recommends taking pupils into our confidence about the purpose of experiences to challenge their existing views.[14] She makes the point that the concepts taught in school were formulated from the formal models of physics, and that we need more simple concepts which relate to simpler models appropriate to pupils.

BATTERY

In their earliest experiences of batteries pupils often think of the battery as a unipolar 'giver' of electricity. It seems that pupils generally think of the battery as a store of electricity or energy.[10] They see it as delivering a constant current in a closed circuit, rather than maintaining a constant voltage or potential difference.[16] Indeed, pupils have very little notion of voltage or potential difference and the battery was seen as storing a certain amount of electricity by 85 per cent of a group of 400 German secondary school pupils.[17]

CURRENT AND VOLTAGE

Osborne and Freyberg,[8] working in New Zealand and in the USA, found that pupils think of current as synonymous with electricity and

electrical energy. Likewise, 87 per cent of von Rhoneck's sample of thirty-seven German secondary pupils thought that current is energy.[18] It appears to be envisaged as a quasi-material. Among these pupils voltage was seen as the strength or force of the current.

Current is usually introduced to pupils as the primary concept and they tend to think of voltage as a property of the current rather than as a precondition for a current to flow.[19] Indeed, Maichle[17] found that in a sample of some 300 German secondary pupils 23 per cent thought that voltage and current are the same thing. It follows that pupils expect voltage to increase as current increases. They are very reluctant to believe that, if no current is flowing, there can still be a voltage between two points.[18] Plenty of experience is advised, with both ammeters and voltmeters in simple circuits, in order to erode the 'voltage equals current' idea.

Some researchers[19 20] have suggested that the usual early focus on current gives rise to the 'voltage equals current' idea and that attempts should be made to make pupils 'voltage-minded' by introducing voltage first as a property of the isolated battery.[10 16 18 19 20] Von Rhoneck proposes a lot of experience in handling a voltmeter and predicting and then measuring voltages so as to establish the voltage concept.[18] Psillos *et al.*[10] support this suggestion and propose a lot of measuring of voltage alongside current measurements, so as to establish the independence of these concepts. They advise teaching only about voltage, and not about potential difference or electromotive force. They also advise against pupils measuring the voltage distribution in a circuit on the grounds that it can lead to the idea that voltage is consumed.

CIRCUIT

Problems in the sequential model of a circuit

Pupils usually think of the circuit as a series of happenings as electricity leaves the battery, travels through the components and returns to the battery. Shipstone[1] finds that some 80 per cent of 13-year-olds hold a sequential view. Tiberghien[3] suggests that an emphasis on current is what leads to this sequential reasoning in that it involves tracing flow as though events were sequential, and several researchers suggest an introduction to electricity which focuses upon energy as well as current.[1 3 20 21 22]

The sequential model is one which is prompted and supported by many life experiences involving cause and effect. However, it prevents pupils from thinking of the circuit as a complete system and it doesn't allow them to think of the interactions when a change in one place affects the whole circuit, and not just that part 'downstream' from the

change.[3 15 22] A sequential model allows the idea of electricity standing, but not flowing, in unconnected wires and it does not account for the instantaneous lighting of a bulb when the circuit is completed.

Working with series and parallel circuits

The importance of treating series and parallel circuits separately and at different times before going on to treat them in conjunction is stressed by van Aalst.[23] He proposes separating sessions of electricity work by interposing work on something else as a way of allowing ideas to become established before they have to be related to others.

The use of analogies

Research has been done on the various analogies used to help pupils to take a holistic 'complete system' view of the circuit. It recognises both the value and the problems inherent in these analogies. Of course, not all analogies are introduced by the teacher. Pupils themselves naturally use their own life experiences as analogies to help them to make sense of circuits and many of their mental blocks are formed around their own self-generated analogies. However, hydrodynamic, thermal and mechanical analogies have all been found useful to some extent.[11 24]

Schwedes[25] has drawn attention to the value of water circuit analogies, but only if pupils have sufficient experience and understanding of the way the water circuit itself works. There are issues in rate of flow, seen as velocity or as volume, which present traps in themselves, and students may see the battery as a 'high point' with current (water) running off both sides. Russell[26] found that, among Malaysian pupils using the water analogy, only 33 per cent saw its value, only 27 per cent used the analogy to explain events, and only 6 per cent used it correctly.

Given pupils' difficulties with heat and temperature any teacher is likely to think twice before offering a thermal model as a helpful analogy, and there is the danger of going round in circles, using problem situations to try to shed light on problem situations. Given Osborne's work in using body circulation to help understanding of the circuit, it is interesting to note that there is even a reference in the medical literature[27] to trying to help students to understand the heart and blood circulatory system by offering the analogy of the electric circuit!

However, researchers suggest the use of mechanical analogies[11 28] such as the bicycle chain, a transportation belt or workers pushing a train around a track. The importance of using multiple analogies is also stressed.[29] The analogy of workers pushing a train around a track was found to support the adoption of the model D view of the circuit,[11] and

Hartel[28] recommends the bicycle chain 'stiff ring' analogy because it helps pupils to recognise that all points influence all others. This is one of the critical concepts and it appears to be particularly difficult to establish against pupils' natural inclination to a sequential model.

Representing circuits in drawings and diagrams

Circuit diagrams can be seen either as pictures or as abstractions but it is clear that pupils often find it hard to recognise the circuits in the practical situation of real equipment. Moreover, Caillot[30] found that students retain from their work with diagrams strong images rather than the principles they are intended to establish.

The topological arrangement of a diagram or a drawing presents problems for pupils which are easily overlooked.[22] It seems that pupils' spatial abilities affect their use of circuit diagrams: they sometimes do not regard as identical several circuits, which, though identical, have been rotated so as to have a different spatial arrangement.

Johsua[31] found that diagrams are often interpreted figuratively, as a system of pipes, and that potential differences are rarely recognised. He also found a tendency for pupils to see resistances in the circuit as 'useful'. Likwise, a resistance which was not seen as 'useful' would not be drawn in the circuit.

Niedderer[32] found that pupils, when asked whether a circuit diagram would 'work' in practice, more often judged symmetrical diagrams to be functioning than non-symmetric ones.

ESTABLISHING AND DIFFERENTIATING CRITICAL CONCEPTS: DEVELOPING AN ENERGY VIEW

Pupils tend to start with one concept for electricity in a direct current circuit: a concept labelled 'current', or 'energy' or 'electricity', all interchangeable and having the properties of movement, storability and consumption.[1 10] Understanding an electrical circuit involves first differentiating the concepts of current, voltage and energy before relating them as a system, in which the energy transfer depends upon current, time and the potential difference of the battery.

The notion of current flowing in the circuit is one which pupils often meet in their introduction to a circuit and, because this relates well with their intuitive notions, this concept then becomes the primary concept.[16] The result of this tends to be that when voltage is introduced it is seen as a property of current.

Psillos *et al.*[10] point to the need for particular effort to introduce voltage initially as a property of the battery, a precondition for current

to flow and present even when no current is flowing. In this it could more easily be differentiated from current.

Von Rhoneck[18] found in a group of thirteen pupils that eight of them thought of voltage as a force and that all thirteen of them thought of current as energy. Clearly pupils' notions of the relationship between force and energy can have bearing on their views of electrical energy.

The earliest idea of resistance is of a 'hindrance' – a barrier to the flow of charge. Shipstone[1] explains how pupils think of a resistance affecting only parts of the circuit 'downstream', coupling their idea of hindrance with the notion of the sequential circuit in which the current is influenced by each circuit element in turn.

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