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Electricity for primary school teacher education

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Abstract
During 1994-5 the Institution of Electrical Engineers together with the Understanding Electricity Educational Service funded the development of a research-based pack of teacher education materials 'Current understanding: electricity concepts and practice for primary and non-specialist secondary teacher education'. The project was carried out by the Primary School Teachers and Science (PSTS) Project based in Oxford University Department of Educational Studies. This paper describes the rationale for the project in terms of current developments in primary science education in the United Kingdom. It goes on to outline ways in which the materials produced differ from previous resources for teacher education in this topic area, and describes the structure of the pack with three main sections dealing with (i) electricity and simple circuits, (ii) very simple electronics, and (iii) pedagogy. Examples are given of findings from research and trials carried out as part of the project, and of ways in which these findings were used to inform the development of the materials. Principles underpinning the development of the work on electronics are presented, again with examples of content illustrating the approach taken. Final sections cover aspects of the materials dealing with pedagogical issues in the teaching of electricity.

Introduction
This paper describes the development and content of a set of research-based teacher education materials concerned with electricity and simple electronics. The context for this project is the advent of a National Curriculum which makes significant demands on primary school teachers' understanding of scientific and technological concepts. In recent years considerable effort has been invested in the development of materials to help primary school teachers improve their understanding of science concepts e.g. various publications of the Primary School Teachers and Science Project and the National Curriculum Council. These materials have been criticised on the basis of omission of any reference to classroom transactions.

There is now a growing consensus amongst those concerned with primary science teacher education that developing teachers' subject knowledge is not of itself enough to improve pupils' learning. The key issue is how teachers can make this knowledge accessible to pupils: what factors affect children's learning of a particular concept; how can teaching take account of this; what analogies, metaphors, language, activities and experiences can be used to promote the learning of a particular topic by children at different stages of development?

This latter kind of knowledge - knowing how to make subject knowledge accessible to children - is known in the education literature as pedagogical content knowledge. In recognition of the inadequacy of tackling subject knowledge alone, the materials described here encompass key aspects of the teaching and learning of electricity as well as the development of teachers' personal understanding of electricity concepts.

Why another electricity project?
This is a valid question to ask, since numerous projects in recent years have produced materials on electricity for primary science e.g. Circuit Training from the Institution of Electrical Engineers, and Electricity and Magnetism from the Nuffield Primary Science project. The work we describe here is different in five ways from what has been done before.

1 First, and reflecting the concerns described above, about a third of the materials are concerned with pedagogical content knowledge and other aspects of the teaching and learning of science.
2 Initial research was carried out to determine teachers’ preconceptions in this topic area. The materials specifically address areas of conceptual misunderstanding and difficulty uncovered by this research, and in addition incorporate findings from the large number of studies carried out with children.

3 An important feature of the materials is that, while maintaining a purely qualitative approach, they attempt to help teachers acquire deep insights into why circuits behave as they do. Previous materials for teachers at these levels often provide little more than procedural knowledge e.g. how to connect up a particular circuit. Our work is very much concerned with concepts as well as procedures, and tries to answer the many difficult questions which, in our experience, primary or non-specialist teachers ask about circuits.

4 The materials are suitable not only for primary teacher education but also for the increasing number of science teachers in this country who are (or will be) teaching outside of their subject specialism at secondary level.

5 Initial work on basic circuit concepts is used and reinforced in the context of very simple electronics. This enables the distinction between science and technology to be emphasised, and means that the materials are relevant to the teaching of both science and technology.

Content
There are three main sections in the materials. The first is concerned with developing teachers’ personal knowledge of electricity and simple circuits; the second extends this work into technology by providing a simple introduction to electronics; and the third deals with pedagogical issues. In addition there are appendices on language in the teaching of electricity, understanding electrical safety, background notes for experts (explaining and justifying the approach taken), the equipment needed and precautions necessary to make experiments work well.

In the rest of this article we briefly describe aspects of each of the main three sections.

Electricity: using the research base
The research explored teachers’ understanding of electricity using a mixture of questionnaires, interviews, and discussions during trials. A range of understanding of what electricity meant to teachers, and the mental models used to explain it emerged.

The teachers could roughly be divided into three groups. The first group were the most naive and they saw electricity as the ‘power’ to ‘do things’. They could offer no explanations of how or why and they used ‘power’ in an everyday rather than a scientific sense. The second, and most common, group had some scientific concepts. They knew that electricity needed circuits and that there was ‘something flowing’ but they did not know what or why. Words like ‘force’ and ‘energy’ were used unscientifically and indiscriminately. They knew that ‘current’ and ‘voltage’ had something to do with electricity but they could not differentiate between them. The third group were approaching scientific understanding. They knew that ‘current’ is associated with the thing which ‘flows’ and that ‘voltage’ is associated with ‘strength’ of electricity.

There were many specific misconceptions. For example, of the teachers who associated electricity with something ‘flowing’ the vast majority thought that the thing which flowed emanated from the battery; many of the teachers thought that the electricity was ‘used up’ in the circuit, so that there would be either less, or no, electricity flowing after a device e.g. a bulb.

Section I of the materials aims to develop conceptual understanding of electricity and to address specific misconceptions. The bulk of the section consists of activity cards and explanation cards, although self-assessment material and summaries of research findings are also included. The activity cards describe activities to do and present these in the form of a conversation between cartoon type characters (figure 1). The explanation cards make extensive use of diagrams and analogies.
The research revealed the importance of not making assumptions about teachers’ prior expertise and understanding. A particular difficulty encountered concerned the use of leads. Several teachers found it difficult to equate leads, covered with plastic and with plugs on the ends, with a straightforward length of bare metal wire. As one teacher said ‘these plugs [leads] don’t look like wires’. Many of the teachers needed reassurance that the colour of the leads, that is the plastic coating, did not matter, and that leads of different colours behaved in the same way. Similar difficulties were encountered with the use of battery and bulb holders and equating circuits in which these are used with ones using just lengths of stripped wire attached to bulbs and batteries. The early activity cards make these links explicitly as teachers move from connecting up circuits with ‘naked’ batteries, bulbs and wires to the use of battery and bulb holders and leads with plugs.

The first explanation card deals with the nature of electricity and specifically addresses the misconception of electricity emanating from the battery. Electricity is described in terms of the flow of electrons. Electrons are a constituent of all matter and are there in the wires all the time. The battery provides a push to make the electrons move. This idea is explained by developing an analogy between a bicycle chain and an electric circuit (figure 2). Subsequent explanation cards use a range of further analogies to introduce the idea of electric current and the behaviour of series and parallel circuits.

Figure 1: Extract from an Activity Card showing the style of presentation

Figure 2: The bicycle chain analogy for a simple circuit
All of the diagrams in the section which show electrons in wires have been deliberately drawn with no edge (see, for example, figure 3). This is in response to the research which found that of those teachers who understood electricity in terms of something flowing many thought that it was flowing in tubes, like ‘blood in blood vessels’, and that the tube has a ‘solid’ edge. Some teachers thought the edge was the plastic coating of the leads. The ‘no solid boundary’ diagrams have been drawn to emphasise that electrons are a fundamental constituent of all matter.

Electronics: from science to technology

This section of the materials is based on inservice work that one of the authors has been carrying out with primary school teachers for several years. Both past experience and the trials for this particular project show that the work is well within the capabilities of primary teachers and is greeted with great enthusiasm. The section is divided into four workshops: Introducing some useful components; Fun with switches; The reed switch and relay; and More projects. Each of these workshops has accompanying but separate Explanations, answers and project solutions sheets which can be used as follow-up reading to reinforce the ideas introduced practically in the workshops.

Principles
The principles underlying the design of the electronics work are set out below.

1. The only background knowledge needed is that of current flow in series and parallel circuits.

2. The opportunity is taken to distinguish between electricity in science and technology. Teachers are introduced to the idea that, in the former, the concern is with the concepts necessary to understand and explain the behaviour of circuits as a goal in its own right. In technology, however, the purpose is the use of available resources to solve problems which meet human needs. Hence there is a problem solving emphasis: the concern is with how a device behaves and then putting it to use.

3. New devices are introduced one at a time, their behaviour explored, and then used in simple projects. The particular devices introduced are: the light emitting diode (LED); the resistor; the light dependent resistor (LDR); the buzzer; the motor; the push-switch; the single pole double throw (SPDT) switch; the reed switch; and the reed relay. These are all available pre-mounted on boards from many suppliers of school science and technology equipment. Arrangements have been made with one well known supplier to make the set of boards available as a packaged kit for the project.

As the workshops progress, more devices are available to solve problems, so the projects can become more complex and challenging. An example is given later.

4. A key point is that the electronics work reinforces and develops the ideas introduced in Section I on electricity, but using a greater variety of devices and circuits and with a problem solving emphasis. The approach is not based on building circuits according to recipes, but on understanding ideas and using these to design solutions to problems.
Project D2

Early sleeper’s doorbell

A push switch on the front door and one on the back door of a house must cause a doorbell to ring. Build a circuit to do the job.

If you go to bed early, you do not want to be disturbed by the doorbell. Modify your circuit so that the bell is disabled at dusk.

Figure 4: Example of a project with a possible solution to the second part

Example of a project
Figure 4 shows the Early sleeper’s doorbell project from Workshop D, together with a solution to the second part. The key ideas this builds upon are the use of switches in parallel to make a simple OR circuit and the role of an LDR in changing the resistance of a circuit. Teachers in the trials suggested that they might use this kind of project with children in one of two ways. A bottom-up approach would involve introducing the necessary circuit ideas and devices and then designing and testing solutions to the project. Alternatively, some teachers suggested that they might use a top-down approach in which children first build the solution and the subsequent work revolves around extracting and understanding the concepts underpinning the working of the circuit.

Pedagogy: teaching knowledge for electricity
Section III of the materials identifies ways in which teachers can enhance their teaching and effectively develop children’s learning. The teachers’ improved understanding gained from Sections I and II is identified as ‘subject knowledge’ and the nature of ‘pedagogic content knowledge’ (called, for simplicity, ‘teaching knowledge’) is described with special emphasis on an awareness of children’s existing ideas and the need to, in Ausubel’s words, ‘start from what the learner already knows’. Teachers are reminded of children’s conceptual models for electric current, already met in a Section I review of research findings about electricity. As a final task, they are asked to diagnose children’s ideas in terms of these models from examples of their drawings of circuits.

A discussion of the nature of science is included in the materials because of the notably inductivist views of science found in primary teachers in recent studies. Ideas about ‘discovering’ scientific ‘truth’, the nature of scientific explanations and the role of refutation are discussed. Examples are given of changes in ideas during the history of science. Science is described as a means of developing explanations of the world and testing them to see if the evidence supports or refutes an explanation, in contrast to technology which is concerned with using resources, including scientific knowledge, to solve real problems for human beings.

The recent shift in primary science education from a mainly process approach to one in which there is a much greater emphasis on the learning of concepts has profound implications for teachers’ practice so this is...
strongly emphasised. The view propounded is that the processes of science should be taught, not as ends in themselves, but as a means by which children's minds are engaged to develop a deeper understanding of the concepts, explanations and purposes of science.

In deciding how to plan what one actually does in the classroom, a way of proceeding based on Schulman's scheme of knowledge types\(^5\) is described. For example, curriculum knowledge might lead one to ask what ideas children will have to understand. Subject knowledge enables evaluation of the adequacy of a teacher's own understanding of what is to be taught. Teaching knowledge can lead teachers to anticipate the preconceptions they might encounter in the children or to know which examples or analogies will be useful, what explanations will be satisfactory and which scientific words will be emphasised. Knowledge of learners will affect teachers' decisions about differentiation and classroom knowledge will be drawn upon to group and arrange children.

Factors to be considered in implementing the lesson include safety, familiarisation with equipment, how to elicit children's views and how best to organise resources and focus investigations. As well as giving practical experiences, other strategies described include discussions in which opposing views (including perhaps the scientific view) are contrasted, their merits debated and ideas for new investigations suggested, with time to reflect on any subsequent new views that are constructed. Comparison of previously-held views with post-teaching views enables children to make their learning explicit. The use of appropriate scientific language, the choice of suitable analogies and representations, and the focus of questioning and assessment are other factors in implementing planning which are discussed in the materials.

This section on classroom practice also includes a brief outline of some pitfalls which have become evident from research. Hence teachers are advised to beware of elicitation as an end in itself with no subsequent attempt to move children from their prior conceptions towards the scientific view. They are warned about doing activities for their own sake, and not addressing children's thinking (i.e. a solely process approach). Research findings which indicate a lack of progression and insufficient use of analogy during teaching, and the dangers of making unwarranted assumptions about what children already know or understand (i.e. lack of assessment) are also highlighted.

**The next step**

Having spent a year carrying out this research and development project, we are naturally interested in investigating the effectiveness of the materials produced. Here, by effectiveness, we mean the impact on children’s understanding of electricity. Hence, we are currently engaged in classroom research which is relating progress in children's learning to the teaching experienced. In about a year's time, we expect to publish case studies of the teaching of electricity based on this research.

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