LEARNING SCIENCE FROM TECHNOLOGY

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ABSTRACT

The study explored the possibility that science can be learned from technology and it described the effects of a teaching approach on electric current with learners aged 11 - 15 years. It was based on a constructivist-developmentalist view of learning which recognises that learners bring prior knowledge to science lessons. The nature of that knowledge and how it is incorporated into lessons is believed to influence subsequent learning. The purpose of science learning is seen as developing learners' own ideas into more coherent conceptual knowledge so that learners can make better sense of their world. As technology is a part of that world, its place as a context for learning was investigated. Technology was defined in this study as 'the ways humans use their intellectual capabilities and physical resources to solve problems of survival, well-being and quality of life.' Related to this is a view of science which sees it as problematic, provisional and progressive, and hence different from views of science that are based on positivist-inductivist philosophies. This instrumentalist approach to science provided scope for analogy exploration.

A teaching model incorporating learners' prior ideas was derived from a learning theory which recognised that the principal action in learning occurs when learners generate new meanings. This teaching model used the familiar technology of the learners' culture as a context for learning electric current. Problem solving was strongly featured in the teaching package. This study confirmed that many learners have prior ideas about electricity which are undifferentiated (with respect to current and e.m.f.), and have based their thinking about it on sequential reasoning and on schemata dealing with consumption. These theories and processes of knowing are resistant to change and likely to impede access to the ideas scientists regard as coherent. The task of changing to systems reasoning and of reducing the weight given to consumption notions has been extremely hard for most learners. An intermediate position may be a more realistic achievement at first contact.

A teaching package was designed so that the ideas of 11 - 15 year-old learners could be studied as they followed a course of study on electric current. Its effects were monitored by a range of qualitative research methods in six classroom trials. Some learners adopted new views initially but regressed to their earlier views. Others adopted a new view, and for some this resembled the scientists' notion that electric current is conserved. Significant changes occurred where learners were able to invent analogies and explore the implications of those analogies in a relaxed environment where there was plenty of time. Learners were not able to change from sequential reasoning, nor from their belief that something is consumed; they coped with the latter idea by proposing a two-component system in which one component, the current, is conserved but the other, a "fuel," is not. Changing to a two-component model, called a transitional framework, is thought to be as big a differentiation as can be achieved. Thus it is unlikely that learners would develop a view of electric current consistent with scientific ideas at first contact. Female learners appeared not to be disadvantaged by this approach.

Implications for the pre-service and in-service education of teachers were considered, resulting in an approach which attempts to ensure that teachers are conversant with the philosophical and psychological ideas embedded in it. Guidelines for considering technological systems from which science might be learned have been suggested.

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This study began through my participation in the Learning in Science Project which examined science learning in Forms 1 to 4. The direction that has been taken here is due in no small way to the influences of several of the people who led that Project. I acknowledge with gratitude the ideas and advice of Dr R.J.Osborne and Dr M.D.Carr, and thank them for their guidance through the experimental stages. Suggestions from Professor R.T.White (on methodology), Mr C.R.Tasker (on teaching models), Professor J.Gilbert (on the data) and Mr F.Biddulph (on teacher education) helped to focus my thinking. Dr D.Shipstone provided helpful insights. The methodology used in this study required independent observations to be made. The assistance of Dr R.J.Osborne, Mr C.R.Tasker, Professor W.Welch and Dr C.Gauld was particularly valuable. Dr M.D.Carr patiently guided the development of the thesis.

The topic itself arose from the realisation that teaching for "making sense of the world" would not be straightforward. It seemed that classroom approaches might need to be different from the usual ways of teaching science. That so many teachers were keen to try this approach in the presence of observers was noted as a further example of their professional attitudes to exploring new ways of teaching. I thank Margaret, Robyn, Dianne, Doug, Harry, Beverley and Mike for their co-operation.

If this thesis means anything, it indicates what young learners can do. The learners who were involved in this research freely exposed their ideas and strategies; my thanks go to Sylvia, Natasha, Adrian, Mark, Ian, Stephen, Ivan, Donna, Michelle, Ross and hundreds of others who shared their ideas with me. There is a virtually untapped source of great ideas and sophisticated analysis in the minds of young learners and their willingness to share these makes this approach to research worthwhile.

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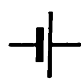
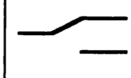
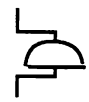
KEY TO THE SYMBOLS USED IN THE FIGURES IN THIS THESIS

Components	lamp or bulb	cell	switch (on/off)	switch (two position)	bell	ammeter
Symbols						

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Chapter 1

TECHNOLOGY AND SCIENCE

Overview of this Thesis

This study is an investigation into the possibility of teaching and learning science from technology. It considers the importance of a technological context in which the science embedded in that technology can be learned.

The aim of this thesis is to clarify the role of technology in learning about electric current. Having considered a definition for technology, and then the relationship of technology to the everyday world of learners, the proposition that technology is a fruitful context for science learning will be advanced. In the next chapter, this idea will be linked to an educationally sensitive view of science, to a recently advanced theory of science learning, and to a model for teaching. The third chapter is a review of the literature on previous research into teaching and learning about electric current. Next a teaching programme is outlined and then its use in several classes is described. The variety of strategies used to describe the effects of this teaching programme included observations and reflections by researchers, in-depth interviews with students and teachers, surveys, and studies over a long period of time with a small sample of learners. Some changes which were made in order to probe further into the learning which had occurred are then considered, and the thesis concludes with discussion of how the programme could be used in schools, and directions for further study in areas such as teacher education and curriculum research.

The Meanings of Technology and Science

There is a number of tasks to attend to in order to clarify and limit the meanings of the terms technology and science. The first task is to establish meanings for these terms, then to distinguish between them, and finally some restrictions will be placed on the meaning of technology.

Clarifying Meanings

The first task is to clarify the meanings of the words science and technology in a way that will be useful in education. To do this it is convenient to look back to the sixteenth century when it would have been a simple matter to define science and technology as two distinct fields of endeavour. Then, science was a philosophical activity, an intellectual exercise of little immediate relevance to ordinary people. Technology was concerned with solving problems and making life more comfortable through the use of tools, or by processes that had been refined by purposeful, thoughtful activity. Thus technology was, and is, in the realm of meeting human needs, whereas science was the development of ways of thinking about the world in order to meet the intellectual needs of its practitioners.

The modern scientific era stems from the times of Galileo and Newton. Science (then called natural philosophy) began with scholars attempting to make sense of the motions of celestial objects. Although science as it is now known was practically absent from European culture throughout the dark ages, technology was present. The development of tools and machines for multiplying the effects of forces, ships for transport, instruments for navigation, ways of preserving foods, and the treatment of some diseases came long before scientific explanations, with their consistent and predictive theories. Technology arose from the experiences of the whole population in a culture.

Developing a Distinction

The distinction between "science and technology" as they are now used can be interpreted in a number of ways; These meanings are explained below.

Theory and application. Science is the theory, technology is the wealth-producing application of the theory. This view is evident in research and development models advocated by scientists seeking funds.

Different status. The important subject science and the ancillary, very minor subject technology, or the pure subject science, the applied subject technology, with the former being worthy of study by only the best brains in a culture, and the latter being for the less able (or for the lower classes). Thus within one of the "two cultures" (Snow, 1961), there is another stand-off, that between scientists and technologists.

Integration. Science-with-technology, by which a user means that it is not necessary to separate scientific endeavours from technological activities. A person may be a scientist in one aspect of her or his work, and a technologist in another; e.g. research engineers, materials scientists, and medical researchers.

A single entity. All those things that scientists do, a general term for a wide range of activities, because science and technology have merged into a new entity.

Alongside these interpretations there is a need to distinguish between scientific technology and non-scientific technology. An example of the latter is the Chinese medical treatment of acupuncture.

Science, technology and the curriculum. Curriculum developers and teachers have largely adopted the second interpretation from the list above. Within the science teaching community there is a particular outlook which favours the study of pure and abstract ideas in preference to the practical problems which beset a civilisation. This is a symptom of what McCulloch

(1986) calls the English disease, in which ivory towers are separated from the real world. That teachers should have this view is understandable, for it has been pointed out that:

> *Nobody denies that technology is central to industrial civilisation. What is sometimes denied is that technology forms an essential part of modern intellectual culture. Indeed, it is often held that technology is alien, even inimical to culture. This is a mistake, one which betrays a total ignorance of the intellectual richness of the technological process, in particular of the innovating one. This mistake has obnoxious consequences for it perpetuates the training of scholars with a pre-industrial cast of mind and conceptual equipment, contemptuous and afraid of whatever they do not understand about modern life. When they wield power... such people try to isolate the technologist as a skillful barbarian who must be kept in his modest place as the provider of material comfort.*
>
> (Bunge, 1973, p.279).

In the history of modern science and technology there are some situations in which the distinction between science and technology was not marked by a stand-off between the two. For example, the climate in which the inventor James Watt and the chemist Joseph Black worked in Jacobite Edinburgh was an unusual period in the history of science and technology. Black had studied the phenomenon of latent heat, and historians are interested in how much his ideas on this had influenced Watt's invention of a steam engine with a separate condensation chamber, and vice versa. For it is claimed that

> *Black and Watt lived in a society that supported a rather subtle understanding of the relationship between the pursuit of understanding and the pursuit of improvement. They had the good fortune to be born into a culture which did not elevate the philosopher and demean the mechanician.*
>
> (Donovan, 1973, p.29).

Black experimented in order to find out how natural processes worked; Watt experimented in order to improve devices. This thesis explores the possibility of establishing such an understanding between science and technology in the school curriculum. In this way, the science programme would be better able to cope with the learning needs of a much broader part of the student population than it presently serves (Ziman, 1980).

Limiting the Meaning of Technology

Yet a further distinction is necessary for the clause "learning science from technology" can have another meaning. Whereas in this study it means the development of understandings of the scientific ideas located in specific items of technology, to others in education it can mean using technological devices like computers to teach science (which this thesis does not address).

Another distinction can be helpful in focusing on technology. The term "technical" is often linked to and used interchangeably with the term "technological". The difference in use here is that technical applies to those skills which are acquired by imitation and repetition and not with any full understanding of their origins and implications. A related term, "craft", describes those activities which require unusual talents and precision, but which make little intellectual demand on their practitioners. Rules of thumb, experience and pragmatism are the bases of knowledge and skill acquisition. While technique and the precise application of skills are often associated with technology, they are not essential to it.

Technology Defined

The discussion has helped in clarifying a definition for technology. In this study it will be defined as follows:

> Technology is the way humans use intellectual capabilities and physical resources to solve problems of survival, well-being and quality of life.

This is consistent with very recent views from English technology in schools groups (Edwards, 1987) and UNESCO (Hall, 1987). Philosophical foundations for this definition are found in this statement:

> *The technologies are the cultural traditions developed in human communities for dealing with the physical and biological environment.*
>
> (Merrill, 1968).

There have been many similar views expressed, for example:

> *Technology is man's effort to cope with his physical environment, and his attempts to subdue or control that environment by means of his imagination and ingenuity.*
>
> (Mitcham, 1973).

Bronowski (1973) recognised the intellectual side of technology by beginning his personal narrative "The Ascent of Man" with the declaration that the human species is the only species which controls its environment rather than being controlled by it.

The Status of Technology in the Curriculum

Trends

From the point of view of teaching science, the problem is to understand why there are so few references made to technological events from learners' environments in science lessons. Those which are referred to are usually added on to the end of scientific expositions, and are rarely followed up with any in-depth treatment. As Black and Harrison (1985) point out, these additions are merely extra knowledge about science, and they are rarely based upon, or linked to, any direct form of experience.

To redress this imbalance, George (1981) proposes that there should be two types of scientific endeavours in education. The first is the science that observes, measures and describes naturally occurring phenomena. The second is the science of the artificial, of human-made materials and devices; in other words the engineering sciences. If the latter are ignored a problem develops; typically educational practice concentrates upon the first type, so that this approach comes to mean science to people so educated. Thus they complete their education with a narrow view of science and with virtually no conception at all of engineering and technology. And so the cycle continues, because teachers come from the first of these groups, and unfortunately technologically-oriented people do not become school teachers, nor do they take any significant part in the machinery by which school science courses are established. This thesis argues that technology is not only a worthwhile intellectual endeavour in its own right, but is also a means by which students could learn science.

Clarifying a Role for Technology in Learning Science

The everyday machines and devices used at home are a part of the familiar environment of young people. Most youngsters have wide experience of these appliances, and as well they have some ideas about how they operate. This experience should be a useful beginning for developing a more complete understanding about how they work and the scientific and technological principles on which they are based. The notion of everyday experience as a context for further learning in science is one of the principal ideas on which this study stands.

Modern views of learning adopted in this research, and stemming from constructivist theories, place considerable importance on the prior knowledge and learning strategies of the learner. The theoretical position which has been adopted in this study is based upon a generative theory of learning (Osborne and Wittrock, 1983; 1985) which recognises that learners have accumulated ideas, theories, ways of knowing, and knowledge through their experiences from an early age about how and why things behave as they do. In the case of science teaching these ideas can be taken into consideration and used by teachers as they prepare instructional materials and as they interact with learners.

The remark that the teacher (of science and mathematics) needs to be a cultural anthropologist, selecting from the learner's environment those items which can be exploited in order to make learning more powerful (Papert, 1980) also supports the main argument of this thesis. Further support is supplied by Holt (1982), who noted that youngsters learn by assembling much experience in a variety of settings before establishing any structure in that data. It is not easy to imagine a more fruitful source of ideas for young learners of science than the familiar technology available in their everyday lives.

Technology in the New Zealand Curriculum

The first European immigrants brought with them elitist elements of the class dependent English education system, and then demanded that it be made to operate in an egalitarian way by being available to all (Ausubel, 1960). Consequently science in schools was taught in the style of lessons in Latin and Greek (Searle, 1958). In the past 80 years there have been several attempts to inject technological (and technical) ideas into the secondary school curriculum. In the 1940s curriculum reforms listed these two topics amongst seven which formed the basis of secondary school science:

> *The elementary chemistry and physics of the pupil's home environment,* **and**
> *The methods and achievements of science and the more obvious effects upon the human community. A glimpse into the technological development of the pupil's environment.*
>
> (Thomas, 1942).

Subsequent science curriculum revisions in 1968 and 1978 required teachers to deal with the "place of science in society". Despite these official statements the direction taken was in fact the opposite one; science continued to be an academic course used primarily to find new entrants to the research-oriented professions (Ziman, 1980).

Likely contributions to the failure of these reforms would include:

1. The absence of a theoretical perspective on technology caused by a mind-set that favoured the abstract and hypothetical in education.
2. The existence of textbooks which did not deal with these requirements and the absence of textbooks and other resources which did.
3. The absence of sufficient in-service education for teachers to confidently implement the new proposals (for the reforms that have occurred in science education usually reflect the ideas of reformist groups which often have tenuous links with current practices in schools).
4. The control of examinations being separate from the reforming groups, and the absence of checks to ensure that new curriculum intentions were implemented.

Technology as a Context for Learning Science

In this study the position being explored is that technology can contribute to the learning of science if:

1. It permits learners to confirm that their ideas are sensible.
2. It helps to make the learner's immediate world relevant through the provision of concrete systems about which to think.
3. It reduces the dependence on abstract notions and mathematical models especially in the introductory and developmental stages.
4. It helps to understand and solve real problems.
5. It lowers the barriers to learning science so that people of non-European cultures are less hindered (for example, through the use of Polynesian technological systems).
6. Learners' form insights into their own ways of learning as the emphasis is shifted from the acquisition of knowledge to the development of intellectual skills.

Beginnings

This study was formulated during the writer's participation in a research project (the Learning in Science Project) set up by the New Zealand Department of Education in 1979. A small group of researchers in the Schools of Science and Education at the University of Waikato and Hamilton Teachers College investigated the learning of science in Forms 1 to 4 (ages 11 to 14 years). The researchers reported previously undefined or ill-defined problems (Osborne and Freyberg, 1985). These problems were centered upon

1. confusions and mis-matches between teachers' meanings and learners' meanings for words,
2. learners' prior knowledge, the tenacity with which it is retained, and the implications for learning if teachers ignored this,
3. the absence of effective strategies for developing intuitive knowledge into more coherent views of the world.

Subsequent investigations include learning and reading in science (Bell, 1985), establishing a place for earth science in the school curriculum (Happs, 1984), the attitudes of learners to science (Stead, 1985), and a constructivist approach to learning aspects of plant nutrition, (Barker, 1986).

A second project, the Learning in Science Project (Primary), built upon this foundation as it clarified and developed the crucial role of high quality interactions between learners and teachers (Biddulph and Carr, 1986). Thus a climate for re-thinking science teaching and learning had been established.

If the purpose of science education is "to help learners to make better sense of their world" (Osborne, 1985) then how could their world be incorporated into science lessons? After some trials the research became an investigation into learning the concept of electric current by learners aged 11 to 16 years (and by their teachers), using familiar technological devices, approaches and problems as the learning context. During the research other projects involving key concepts in physical science were studied, but have not been included in this thesis because the study of electric current soon became a full-scale project on its own. However, considerable work on the second topic, learning heat through refrigeration, has been undertaken, and reported (Cosgrove and Meuggenberg, 1986; Newman, 1986; Cosgrove, Newman and Forret, 1987; Newman, Cosgrove and Forret, 1988). Some of the results of this other work will be referred to in a later chapter. Work on a third topic (learning kinematics from driving cars) is being developed.

Chapter 2

TEACHING AND LEARNING SCIENCE

Introduction

Before reviewing the research into teaching electric current in schools it is necessary to consider some concerns about the aims and purposes of science education in schools, and about teaching approaches (both the presently-used strategies, and innovations which address these concerns) through which a technological context might be translated into classroom action.

A sub-thesis is proposed which deals with both a new view of science in education, and a different way of teaching science from technology. This sub-thesis is a necessary addition to the principal thesis because the dominant views on science presented in schools, and the ways it is taught, are considered to be incompatible with the learner-empowering orientation that this thesis adopts.

Science Teaching in Schools

A number of commentators have expressed major concerns about the aims and purposes of science education in schools. Science in schools has been described as providing satisfactory learning experiences for, at the most, 20% of an age cohort (Fensham, 1985). Others have doubted that any students receive a worthwhile education in science (NZDE, 1978). Most analyses suggest that science in secondary schools is used primarily to select the next generation of practitioners for the research-oriented professions, a minute proportion of the school population (Ziman, 1980). Typically science teaching is considered to be the price of admission to these professions (Claxton, 1985b) with its emphasis, almost exclusively, on the achievement of a high rate of information retrieval, and imitative behaviour, rather than autonomous understanding. The process of science education is seen to be controlled by teachers who were educated in the same way and who are themselves restrained by tightly-examined syllabuses (UNESCO, 1984).

In science lessons, Renner (1982) noted that it was the teacher who decided what was to be learned, how it was to be learned, and at what rate this would take place; learners were provided with a guided tour of the subject. Learners did not operate independently, and they were kept away from contentious or unresolved aspects of the subject, and its social implications. This position may have arisen, in part, because school science is dominated by a hidden curriculum in which:

People's experiences in doing science are principally remembered as an exercise in unacknowledged fraud. The science experiments carried out by pupils are supposed to convince them of the truth of the syllabus, but in practice, quite a lot are going to come up with entirely contradictory conclusions. Now the teacher cannot possibly go along with this or else the whole scholastic process would collapse in farce. So those pupils who have provided what the teacher wants are acclaimed for having got the right answer, the others are denounced for having got the wrong answer....as a result all pupils get a great deal of practice in inventing plausible excuses and even in fiddling their results. These are, of course, valuable human skills...For what the pupils are learning.... is the subtle art of surviving in an organisational hierarchy. Discovering and pandering to the prejudices of your superiors, telling them what they want to know, protecting them from facts that might disturb them, are all components of this important art...

(Jones, 1985).

This might be argued to be a respectable procedure for some purposes (e.g. training in doing a clean experiment), especially if the aim is to inculcate symbolic science (Claxton, 1985b), or to select the people who are to be entrusted with scientific endeavours, by identifying their compliance and cognitive style. These are narrow aspirations; science education is required to do more than this for both the select group and all other learners.

The dilemma of purpose recognised by Fensham (1985) and Ziman (1980) has been further examined by Claxton (1985b). He proposed that one aim was to teach symbolic science (i.e. the science which scientists call science), another was to amplify learners' competence in dealing with natural and technological phenomena. Claxton claimed that these two aims are incompatible, but it is not clear how the second aim is in fact incompatible, or inconsistent, with the first. This conflict is one issue examined in this research since the hypothesis that science can be learned from a technological context closely approximates an hypothesis that amplifying competence might result in a deeper understanding of scientist's science.

Conventional Strategies

The most common science teaching strategies have been described as processes of exposition, accompanied by memorisation; knowledge is transmitted from the teacher to the learners. Renner (1982) considered that orthodox school science teaching might be an effective mode of learning if training is the main purpose. He saw it as a three-stage procedure in which novices are given new information, which is then verified by a selected demonstration, and followed by application of the new knowledge (usually by applying rules).

Similar transmission modes of science teaching have been described, based on observations in New Zealand schools (Tasker, 1981; Cosgrove, Osborne and Tasker, 1982). Sometimes a statement of fact was made by the teacher, and this was followed by a confirmatory experience (e.g. through a demonstration or by introducing an analogy selected by the teacher for its agreement with the statement). Othertimes the teacher provided an illustrative experience of the topic under consideration; learners were required to respond by proposing explanations until a desired idea emerged. From this response the teacher developed a theoretical explanation. Learners were then expected to transfer this explanation to related phenomena themselves. These are memory-based views of learning associated with imparting knowledge. They are closely related to Renner's description of a method of training in science, and they are compatible with the selective assertions of Ziman (1980) and Fensham (1985).

Such teaching approaches can be criticised on the following grounds:

1. They ignore modern ideas which see learning as a process in which meaning is constructed by learners.
2. If any cognitive changes occur at all they are achieved incidentally after much memory work, repeated contact with the same ideas, and drill, and not by structuring (Rumelhart and Norman, 1981) or integration to form new conceptions (Claxton, 1985a).
3. Events from learners' experiences, and the interpretation of events from outside the classroom are incidental to, or are ignored in this approach.
4. Resultant learning does not occur in the way that the teachers intend (Gilbert, Osborne and Fensham,1982; Claxton, 1984, 1985a).

Some Recent Innovations

Science teaching has been to some degree influenced by learning theories which have emerged over the past 30 years. For example, the learning theories of Piaget, Bruner and Gagne have been used to form a framework for the development of new approaches to science teaching (Pope and Gilbert, 1983). A major national science curriculum project, The Australian Science Education Project, ASEP, was based on a segment of Piagetian stage theory, Bruner's structure of disciplines idea influenced the American projects (PSSC, BSCS, and CHEMStudy), and Gagne's hierarchies were incorporated into a process skills approach initiated by the American Association for the Advancement of Science, (SAPA - Science, A Process Approach).

In essence these approaches emphasised the role of the teacher who sought to implant, by sophisticated expository teaching (aided by elegant resources) the scientific principles which would act as foundations for further learning of formal science. Thus they would seem to be efforts in improving the delivery of symbolic science rather than in developing learners' own views. In them the learner continued to be seen as a receiver of science transmitted by a teacher; there was little scope for the learner's own ideas to be considered.

An Alternative View

An emerging view of science learning sees it as a complex procedure in which the learner, at different times, may have to acquire new information, re-organise existing knowledge, and discard cherished ideas (Hewson, 1981).

Here the emphasis is shifted to the role learners play in shaping their own knowledge. Since a developmentalist-constructivist view is adopted here its tenets will be summarised as a basis for a science teaching strategy to be used in this study. An important focus will be on identifying theoretical aspects which deal with conceptual change.

Learning Theories

A Generative Learning Theory

By blending a predominantly constructivist approach to learning with recently emerging ideas on information processing and problem solving, Osborne and Wittrock (1985) proposed a model for science learning, the key postulates of which are:

1. The learner's existing ideas influence how the senses are used to select incoming information.
2. The learner's existing ideas will influence what incoming data are processed and what are not.
3. The incoming and selected information has no inherent meaning as this is constructed by the learner.
4. The learner generates links between the selected input and other apparently related items in the learner's memory store.
5. The learner may construct meaning by linking the new input to previously stored information.
6. The newly constructed meaning may be tested alongside the other information in the memory store.
7. A newly constructed idea may be retained by the learner, or it may be rejected.
8. As it is the learner who generates the links and constructs, validates, and assimilates new meanings, then the individual must accept the major responsibility for her or his own learning.

The postulates of the generative learning theory can be seen in relationship to schema theory.

Schema Theory

The principal tenet of schema theory is that much knowledge exists embedded in specialised procedures (called schemata) which are employed in the interpretation of events in our environment (Carey, 1986). The term 'schema' is a helpful construct in thinking about knowledge, because it suggests a system in which components are assembled into successively more intricate and elegant networks or theories. The theory suggests that learning may take place either by 'accretion' (addition to existing schemata, rather than development of new schema) or by 'structuring' (creating new schemata) (Rumelhart and Norman, 1981). The second process is taken to be synonymous with conceptual change in this study (1).

Structuring occurs when existing schemata are used as models or analogues in the construction of new schemata. Modelling through the use of analogies, metaphors and similes can help learners to develop new schemata in two ways.
Analogy transfer. Concrete analogues are introduced and analysed as a step in solving problems. Relationships may be noticed between a source model and a target through semantic retrieval cues (Gick and Holyoak, 1983). A general schema, encompassing both the source and the target might be produced, enabling the problem to be solved. The availability of several high-quality analogues is probably necessary, as well as a suitable mode of transaction.
Analogy creation. Instead of bringing in models from, say, the teacher's experiences, or from a particular culture, it might be possible for learners to devise, develop and critically evaluate their own.
When a model is being matched to something to be explained, learners can examine the positive, and negative, analogy between the two models and the target. A neutral analogy, whose properties are not known to be positive or negative, may suggest ideas for speculation and prediction (Hesse, 1963).

Dealing With Learners' Views

Learners bring to their science lessons a view of the world based upon their experiences, (which Claxton calls gut science), and usually, another view based upon the influences of language and social systems, called lay science.
For a particular phenomenon the intuitive explanations provided by gut science differ from those provided by lay science, and this incongruence may not be challenged because the two levels have not been connected or correlated. For example, a gut science mini-theory is found in the explanation of day and night as 'the sun rises', whereas a lay science view of the same event might be 'the earth rotates.' When two schemata, or cognate mini-theories (such as these two) are adjacent or overlapped without being linked, they are described as being laminated (Claxton, 1985a).

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(1) The notion of a schema, or mini-theory (Claxton, 1985a), is considered to be superior to the other terms which have come into use in the past fifteen years or so to describe learners' prior knowledge. Misconceptions, preconceptions, alternative frameworks, and children's science are more value-laden as they suggest that learners' ideas are wrong or false, partial or incomplete, or childish.

Learning is seen, in part, as being the detection and resolution of disparities between such juxtaposed schemata of gut and lay science, i.e. changing or developing the lamination towards integration (1).

Claxton (1985a) proposed four ways by which laminated mini-theories can be linked:

1. The two may become integrated.
2. One theory may become subsumed within the other (engulfment).
3. The overlapping portions of each may be extracted to form another mini-theory. (abstraction).
4. One or both mini-theories may be moved out (re-located).

Possibly two or more of these processes might occur in the resolution of a clash of applicability. Of course, learners control these processes. While it has been assumed that learners wish to take part, this may not always be so. An important consideration to be dealt with in promoting conceptual change is to acknowledge that the sociology of the (school) learning environment might overpower other pedagogical determinants (Claxton, 1986, 1989), resulting in learners making a partial or conditional commitment.

A View of The Nature of Science and Learning in Science

Constructivism can be argued to be consistent with modern views of the philosophy of science, particularly if science is seen as problematic and progressive, rather than positivist and inductive.

An Instrumentalist Stance on Science

The view of modern science adopted in this thesis does not come from a single position (such as the refutation approach of Popper (1959), or the scientific revolutions approach advocated by Kuhn (1970)), but is developed in terms of a set of characteristics chosen for their significance for education. This acknowledges Hodson's (1986) advice on the implications of linking changes in the science curriculum to any single view of the philosophy of science.

The synthesis is based upon certain ideas of Popper (1959), Kuhn (1970), Churchland (1979) and in particular those of Medawar (1984), resulting in an instrumentalist stance (that unobservable entities provoke the development of models about which ideas can be organised).

(1) This separation is another example of the utility of Claxton's thinking of these views as mini-theories, for they were previously undifferentiated as 'alternative frameworks' (Driver, 1972), 'children's science' (Osborne, 1985), and even 'misconceptions' (Helm and Novak, 1983).

Thus science is seen by the writer to be:

Paradigmatic	Change occurs and progress is made by revolutions in which one set of world views is replaced by another.
Conceptual	Notions are derived from an individual's experiences; they are not absolute nor inborn, and are modified as they are subjected to reflection and persistent testing.
Progressive	Present theories are considered to be more useful as they have greater explanatory capacity than the views that they have replaced.
Predictive	Powerful deductions can be made since considerable confidence, developed through experience, is attached to the theoretical base of the physical sciences.
Problematic and Provisional	Despite the undoubted success enjoyed by the present theories of science, these theories are improvable and much effort is given to continual evaluation of what appear to be established ideas.
Reductionist and Parsimonious	Rather than developing more theories scientists attempt to develop theories which envelop sets of existing theories; usually the new theories are more abstract, or they may be formulated in mathematical terms.
Public	The worth of scientific theories is debated openly within the community of interest, and others may observe, and participate. While there may be secretive stages (usually where ideas are being evaluated prior to publication, and during intense competition between groups of scientists) it is in the public stages that scientists receive acknowledgement and acclaim for their ideas.

Linking Science with Schema Theory

Schema creation by analogy fits comfortably with this instrumentalist view of science for here the paradigm is also metaphorical (for example, molecules of a gas behave as if they are tiny elastic spheres). The view that science progresses by successive refinements to its metaphors is attractive in education first because it gives status to the original metaphors of novices (gut science) and the cognitive processes by which they were formulated; rather than regarding this knowledge as an obstruction to learning it can be treated as a starting point. Secondly, it gives considerable status to historical views. Thirdly, it suggests that science learning could occur through considering a progression of metaphors, instead of a single step approach of attempting to move learners directly from their primitive metaphors to sophisticated and often abstract metaphors. Thus learning science might happen if learners evaluate a series of increasingly more powerful analogies, metaphors and similes, particularly if the learners could decide which metaphor they consider to be best for them.

School science is often taught in ways that do not illustrate the view of science just described. Some commentators have argued that the present dependence on textbooks for instance, causes a misleading display of the nature of science. For example:

1. Musgrave (1982) considered that science education was misleading because it was unhistorical, in that it neglected the views which preceded the presently-held theories.
2. McCloskey (1982) pointed out that there is much overlap between the discarded theories of the past (i.e. the common sense of earlier scientists) and the present mini-theories of learners in science.
3. Kuhn (1970) expressed the view that science education *remains a relatively dogmatic initiation into a pre-established problem-solving tradition that the student is neither invited nor equipped to evaluate.*

To meet these and other criticisms of the philosophical basis of science education, the seven-point statement was developed. If this statement can blend with a theory of active learning and with effective classroom action, then a broader view of science, which can include technology, will be possible.

Teaching Strategies for Conceptual Change

The central feature of a generative learning theory is the restructuring of schema, or the process of conceptual change. Strategies for promoting conceptual change have been developed by a number of researchers with a constructivist orientation and are reviewed in Cosgrove, Osborne and Tasker (1982) and in Cosgrove and Osborne (1985). Five of these, the proposals of Renner (1982), Karplus (1975), Nussbaum and Novick (1981, 1982), Erickson (1979) and Rowell and Dawson (1983), will now be discussed. A sixth approach (Barnes, 1976) will be contrasted with these, and then a further strategy (based upon the work done in this thesis) which

1. uses technological events and devices chosen from the everyday world of learners,
2. allows for an extensive assimilation process, and
3. attends to cultural and gender effects on learning,

will be described.

Reported Strategies

An extension strategy. Renner (1982) suggested that each learner develops the understandings he or she has about a concept (rather than having these implanted). To bring this about, the teacher first provides suitable experiences for learners to create what is to be learned. Secondly, the learner is introduced to the language of the phenomenon being investigated, and the teacher helps the learner to interpret what has been found, using that language. Thirdly, the new idea is enmeshed with existing knowledge through experiments with unknown outcomes (even though the learner knows the concept that controls the investigation). Thus the learner will have an opportunity to develop personal understandings.

Karplus' learning cycle. Karplus (1975) advocated a developmental process in which the learner is said to be in control of at least a part of the learning process. In the first phase of a three-stage cycle, students learn through their own actions and responses, while the teacher expects little in the way of specific accomplishments, and there is minimal guidance. Learners are expected to raise questions that they cannot answer with their present reasoning patterns. Then the concept is introduced. Here the teacher is more active, and learning is achieved by explanation. In the third stage the new concept is applied to new situations so that its range of applicability can be extended. Learning is achieved by repetition and practice, and in this way the new reasoning pattern has time to stabilise.

In these two approaches learners are required to capture or rapidly form new ideas. The next set place greater emphasis on an interaction between what the learner already knows, and new ideas.

Cognitive accommodation. Nussbaum and Novick (1981,1982) consider that science concept learning involves cognitive accommodation of an initially-held alternative framework. They begin by exposing these alternative frameworks to ensure that each learner is aware of his or her own pre-conception. This is achieved by introducing some event which requires learners to invoke their pre-conceptions in order to interpret it. Learners describe their own ideas verbally and pictorially, and debate the various views represented by their peers in order to better understand the features of all views. Dissatisfaction and discord (also described as **disequilibrium** (Inhelder and Piaget, 1964), **cognitive dissonance** (Festinger, 1957) and **conceptual conflict** (Berbyne, 1965)) cause learners to recognise the need to modify their views. Learners then search for a solution to the conflict and thus accommodate the new with the old.

Resolution of anomaly. Erickson's (1979) three-stage approach starts with helping learners to devise intuitive ideas through a set of experiential manoeuvres, which allow learners to become familiar with a wide range of relevant phenomena. Learners clarify their ideas and develop the confidence to begin to make predictions. This is followed by anomaly manoeuvres, in which an element of uncertainty is introduced, causing learners to re-structure their views. Accommodation occurs in the third stage by group discussions and teacher intervention.

Comparing theories. Rowell and Dawson (1983) suggest a less exposing approach by confronting the differences between the views of children and scientists. First the teacher's questions establish the ideas which children bring to the problem situation. These ideas are accepted as possible solutions, and the teacher puts forward another possibility (the scientific idea) which is taught by linking it to basic ideas already held. Then the old ideas are recalled for comparison with each other, and with the natural world.

These teaching strategies represent considerable advances on the primitive approaches described earlier but they are somewhat restricted in their scope.

Restrictions of These Conceptual Change Teaching Models

Five ways in which these teaching models need to be extended in order to meet the design criteria established here are now discussed.

Teacher's role. These strategies remain teacher-dominated, in that an important role of the teacher is to elaborate on laboratory-based learning in order to fit the scientists' explanation to that learning. In this role the teacher would face considerable difficulty if learners had widely diverse prior experiences (for example, as Kelly (1981) and Stead (1985) have indicated, for female students and Polynesian students respectively). If conceptual change is to take into account the learners' prior views, and their previous experiences, then the process may have to be less teacher-driven.

Status of learners' views. Learners' views are undervalued. When teachers approach conceptual change with the intention of exposing learners' views in order to contrast them with the scientists' view, the learners may realise that the scientists' view is going to be revealed after their inadequate ideas have been exposed. Thus a traditional game of the science lesson, in which learners confess their ignorance before the 'great idea' is revealed, will continue to be played.

Outcome. A single outcome is anticipated and the procedure is the same for all. These models are reluctant to allow for multiple outcomes; learners are expected to reach the scientists' views at the same pace. But for many learners the pathway along which they must travel to master a significant scientific concept can be a particularly steep one. Provision of one or more intermediate resting points (transitional frameworks in this study), which could also be accepted finishing points for some learners, may be necessary.

Stabilising new views. There is insufficient time and depth for the stabilisation of the new concept. If new concepts are to be stabilised so that their usefulness and fruitfulness can be established, then a lengthy period may be required. This may not be achieved in a single block of time; re-visiting in succeeding years may be necessary. Further exploration will be block of time; re-visiting in succeeding years may be necessary. Further exploration will be important to establish links to related concepts (which in the case of electric current include resistance, and electromotive force).

Attitudes. Learners' attitudes are insufficiently addressed. The attitudes of learners have been largely neglected in science education. Claxton (1986, 1989) points out that the process of conceptual change is a daunting one. Peer pressure and other cultural constraints affect the learner as he or she makes a decision whether to take part in learning. The costs are compared to the perceived benefits, and this can result in rejection of the learning pathway proposed, or the learner may adopt a compromise position in which he or she memorises the teacher's material without adopting it. The learners' pre-conceptions are not then modified, or modified in an uncontrolled manner.

A Further Strategy for Conceptual Change

Towards a New Strategy

In another developmentalist-constructivist approach to teaching, the outcome is less contrived than in the previous set of teaching approaches. In this problem solving approach, Barnes (1976) proposed a four-stage learning cycle in which learners take a prominent part in the formulation of their own knowledge, independently of the teacher. First, learners attempt this by working in small groups to present their preliminary knowledge. Next there is an investigation stage, with much discussion and other activity, including experimentation. Then in a re-organising stage, the teacher focuses attention on the problem to be resolved and tells the groups how they are to report back. Finally, in the public stage, the groups of learners present their findings to one another, and this leads to further clarification by discussion.

Barnes' strategy approaches the conditions which the writer requires in order to attempt conceptual change because it allows learners to be in control of the learning process. However it does not deal specifically with conceptual change, rather it leads up to such change.

The New Model

The teaching model developed for this thesis explores a number of the issues raised above, and builds on points in these strategies. It will be described by outlining the following features of the strategy:

1. The role of teachers.
2. Learners' attitudes.
3. Specific activities in each of the three phases of the strategy.

Role of Teachers

The model sees a role for teachers which is more complex and more subtle than the demands of conventional transmission teaching. Important new activities include:

Identification and clarification of views. On any particular concept, the teacher needs to understand the learners' views, the scientists' views and her or his own view on the concept. In the classroom teachers will need time to elicit the views children bring with them to their science lessons, and to clarify these views alongside various scientific (including historic) views on the topic or concept being studied. While it might be reasonable to assume that teachers and scientists have the same views there is evidence that this is not always so. Shipstone (1984), in studying the persistence of fallacious models of electric current, noted that 39% of a group of physics honours graduates training to be teachers retained a non-scientific model of electric current.

This teaching model recognises that there will be a range of views, that it will take time to elucidate them, that the teacher will need to know how such views originate and how they bear on subsequent learning. The capability to ask questions in a subtle way, moving from broad to sharper questions will be a key teaching operation.

Provision of experiences. Learners will need to experience fully the phenomenon under discussion. This may take many lessons for some learners with less experience and, therefore, require consideration of other experiences for those with a stronger background. Kelly (1981) points out that one very important way in which girls and boys differ when they begin secondary school science is in their prior exposure to scientific situations. Boys' toys, often incorporating electrical and electronic effects, help them to develop physics-related skills, or at the very least they provide a familiarity with physics. An issue of equity is addressed by providing extensive practical experience.

Facilitating communication. If self-clarification of the learner's views is to occur the teacher will need to provide a supportive environment, so that learners are not threatened in revealing what they feel are partially developed, incomplete, and possibly inadequate ideas.

Promoting the evaluation of views. The learners will need to be provided with opportunities to debate the advantages and disadvantages of their ideas with each other.

Introduction of other views. Usually the teacher would present the scientists' views if the learners had not. The teacher might however introduce an intermediate view (transitional framework) which would often be an historical view in order to provide a stepping stone towards the scientific concept.

Helping learners accommodate new views. The teacher will need to devise activities which enable or require the learner to use any newly-acquired view to explain other phenomena. If these activities challenge learners to find answers to a realistic and culturally-sensitive set of practical problems then learning can be enhanced. Suitable technological devices and problems should play a crucial role in meeting this need. In this way the matter of context is attended to.

Learners' Attitudes

Attempts to bring about conceptual change were not regarded as cognitive challenges alone. The attitudes of learners were to be considered as well. It was planned to proceed on the basis that learners' self-confidence was not to be jeopardised or damaged, irrespective of the learning outcomes. This was approached by planning to meet the following recognised effects of familiarity and confidence on subsequent learning.

How learners respond to new information. Young learners, on entering a new field, explore it by collecting as much data as they can (Holt, 1982), and subsequently their ideas which unify, link and interlock the data emerge with familiarity and confidence.

The advantages of prior experiences in learning. From classroom observations, Alton-Lee (1983) noticed that learners' achievements in a given area are correlated more strongly with their prior experiences in that area, and rather less with teachers' expectations from previous successes. Thus, students with few prior experiences would be disadvantaged, relatively. Kelly (1981) and Stead (1985) compliment this finding with their reports that female students and Polynesian students respectively can be disadvantaged by cultural biases (against the physical sciences) which may result in both groups having few experiences on which to base further learning compared with male European students.

This presents a teaching challenge for it may take great skill for a teacher to acknowledge that disadvantaged learners may be quiet and reserved, in contrast to the advantaged, experienced group (which might detect the advantage it possesses and seek to exploit their position).

As well as addressing attitudinal effects through the provision of extensive experiences, there is a cognitive effect which can be attended to.

Possible permanent defects from restricted opportunities to learn. Lack of experience might result in a permanent loss of learning as happens in some learning processes (Young, 1987). If not, the bias and deficiency might be re-dressed by an initial teaching approach which provides many activities. In this way these learners can build up their own data bases by becoming familiar with events and ideas through concrete experiences.

Specific Activities in Each of Three Phases of the Strategy

The teaching model which has been developed here promotes

- clarification of learners' views
- modification of those views using scientific practices
- exploration of new views within the context of learners' cultural backgrounds.

In common with many of the teaching models reviewed earlier, it has three distinct phases.

Phase one: Focus.. In the first phase the teacher brings the concept into focus by

- establishing a context
- providing motivating activities
- participating alongside the learners
- asking personally-orientated questions

- helping to interpret learners' responses
- assisting learners to clarify their own views.

Phase two: Challenge. In the second phase the teacher challenges the learners to explore their own views and the implications of those views by

- bringing about an exchange of views
- ensuring that all views are considered
- discussing the implications of these views
- helping learners to validate favoured views
- confronting learners with evidence not previously considered
- putting forward alternative explanations, such as historically interesting views, or transitional frameworks, which can help learners to make the connections between various views more readily
- helping to generate analogies and metaphors with which learners can become comfortable and then used to critically inspect the new view.

Phase three: Application. In the third phase, the teacher helps the learners to evaluate new views they may have adopted by

- supplying problems which are most simply and elegantly solved using the new view
- assisting in exploring the implications of the new view
- promoting fluency in reasoning with the new view
- contrasting the new view with the previously held but now less favoured views.

The three phases of this teaching model are presented diagrammatically (Figure 2.1). The first column (from the left) shows the framework. The second column illustrates what the teacher and learners do. The third column relates the model to the generative learning theory. The fourth column extends the relationship to Claxton's synthesis of schema theory within a developmental view of learning.

Conclusion

An instrumentalist view of science has been linked to learning science within a technological context. A teaching model, based upon a developmentalist-constructivist learning theory, which is consistent with this view of science, has been devised to present a science topic in classrooms. Before designing a teaching package, it is necessary

1. to review present practice on what is taught and how it is taught,
2. to examine research into learning and teaching electric current, and
3. to decide on the aspects of this topic which will be studied.

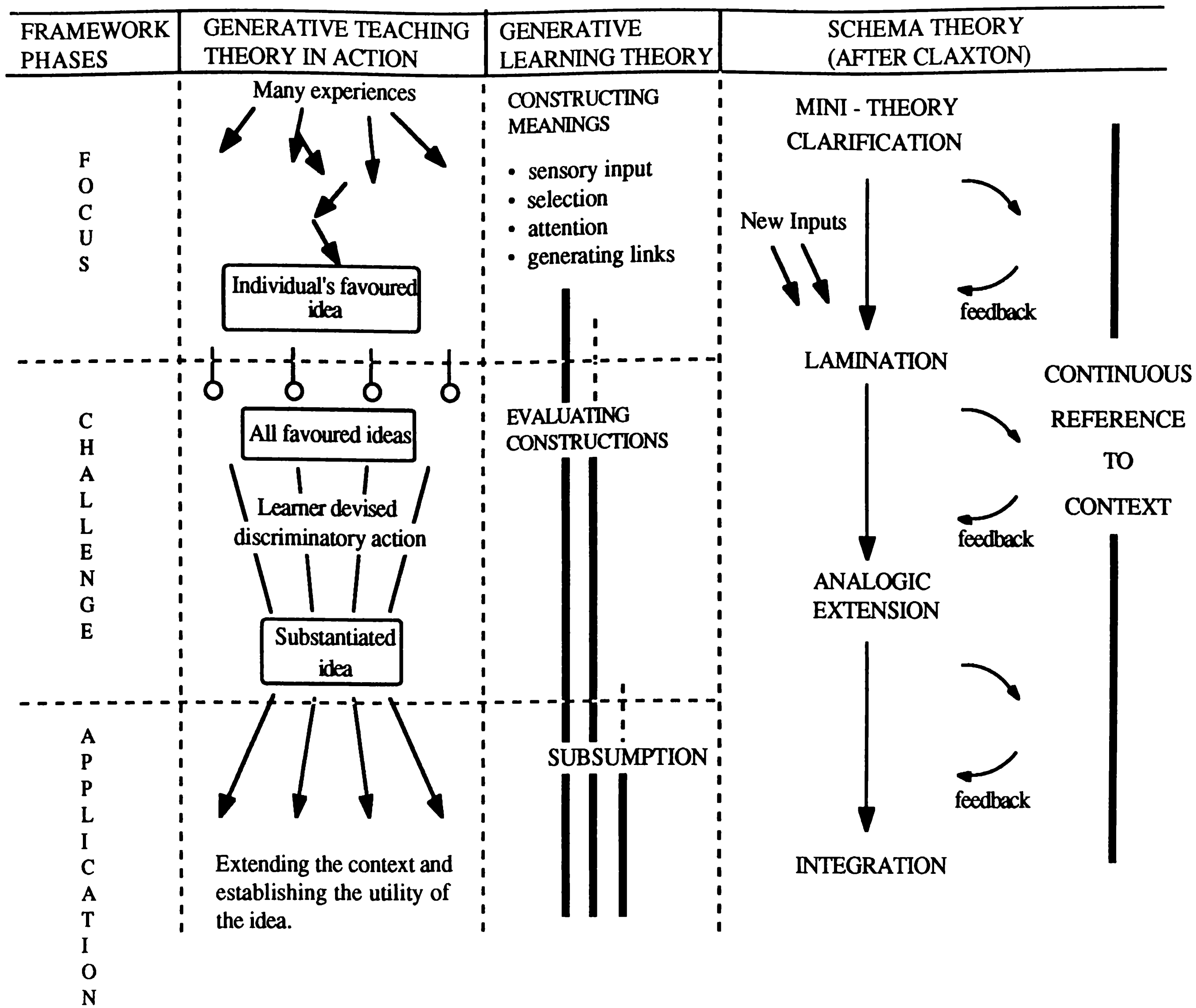

Figure 2.1: Diagrammatic presentation of generative teaching and learning theory and schema theory.

Chapter 3

TEACHING AND LEARNING ELECTRIC CURRENT

A student could learn Ohm's law, which indicates that current in a circuit is directly proportional to voltage. However this proposition will not be meaningfully learned unless the student has meanings for the concept of current, voltage, resistance, direct and inverse proportion, and unless he or she tries to relate these meanings as indicated by Ohm's law.

(Ausubel, 1985)

Introduction

This chapter is in three parts. Part 1 focuses on what is known about teaching and learning electric current in New Zealand schools, through a description of the content and the location of this topic in the school curriculum, the methods by which it is taught, and problems in teaching and learning it reported by teachers.

Part 2 is a summary of research; it is in five sections. The first is about issues in learning the topic. Then there is an account of the outcomes of significant classroom-based investigations. The third section presents insights from problem-solving studies (which is linked to the main thesis of considering a place for technology in the science curriculum), the fourth section reports on explorations of analogy (which is related to an instrumentalist outlook on science and to an aspect of cognitive psychology). In the fifth section, results of studies of learners' prior knowledge and intuitive views are recorded.

Part 3 establishes another approach by blending the points made in Part 2 with the ideas on technology (from chapter 1), and science and learning (from Chapter 2). Finally, the specific aspects of electricity that will be investigated in this research are described.

Present Practice

The Location of Electricity Topics in the Curriculum

In New Zealand schools, electricity is taught to 11 - 16 year old learners (Forms 1 to 5) in three separate episodes as shown by the official prescription for each (Appendix 3.1).

At the first (Form 1 or 2) and second (Form 4) levels, the approach is to provide a wide set of experiences without especially attempting to clarify any particular concepts, such as current, resistance or electromotive force, in contrast to Ausubel's dictum. In the third level (Form 5), Ohm's Law is learned, together with some electronics ideas, e.g. diodes.

Summaries of the programmes for teaching electric current to the middle of these three levels were elicited as part of this study, and are presented in Appendix 3.2. For example, a teacher participating in an aspect of the present research noted that he understood the purpose was to provide an introduction by

> *completing a Cook's tour of a wide range of aspects of electricity within about four weeks, in which pupils are guided fairly swiftly through the content.*
>
> (transcript from an interview).

Topic components. The components of the Form 4 episode are a review of atomic structure, electrostatics, conductors and insulators, current flow and circuits, measuring current and energy, making electricity, magnetism and electricity, electric motor and generator, and electrical safety in the home.

Teaching methods. The teacher reported that the predominant ways of teaching these topics are by demonstrations and note-writing. He stated that the methods in use are based on those from formal Physics courses (which start at Form 6). These are textbook-driven, with the main strategy being practice in handling the laws of Ohm and Kirchoff, applied algorithmically. This viewpoint is collaborated by Armstrong (1985) who noted this example in a widely used physics textbook:

> *A 25-W, 120-V light bulb and a 100-W, 120-V light bulb are connected in series across a 240-V line. Assume that the resistance of each bulb does not vary with current.....*

Then some questions were asked about the current and the power in this system. Armstrong pointed out that this is an unrealistic question, for resistance does vary markedly with current. Under the conditions described in the textbook the 25-W bulb would burn out almost immediately. Furthermore, the problem is quite unrealistic because few people would ever consider doing this physically; light bulbs are almost always wired in parallel in technological as well as domestic situations. Thus, the assumption that learners are directed to make in developing their answer is likely to steer them away from using common sense in thinking their way through to an answer.

Learning Problems. These teachers considered that:

1. The topic is difficult for many learners.
2. There is a perceived pressure to complete a prescribed list of topics.
3. There is learner confusion in practical exercises.
4. There are too many points to be taught.
5. The outcomes of the first episode in Form 1 or 2 are rarely used as a basis for learning in the second, in Form 4.

Questioning the Location of Electricity Topics in the Curriculum

It could be suggested that the way to deal with difficult topics is to delay their introduction until learners are more mature, or more proficient in mathematics. This may be a realistic position in dealing with some topics, such as relativity and quantum mechanics. Some researchers consider that too great a delay in dealing with electric current may result in some learners being unable to change their gut and lay science views (as discussed in Chapter 2). An implication of not dealing with learners' intuitive notions with the intention of increasing their scope and power, Osborne (1985) noted, would be the 'ossification' of that intuitive knowledge so that later it cannot be incorporated into broader theories. This view is consistent with a notion of loss of mental plasticity as maturity is approached, advanced by Young (1987).

Research

Learning this topic is recognised as difficult by researchers as well as by teachers. Some of the reasons for this have been uncovered by recent research reports.

Researchers' Views of the Difficulties in Learning Electricity

The conceptual knowledge about electric current displayed by people who have undertaken an advanced education in physics has been stated as being unexpectedly poor by Cohen (1983) and Shipstone (1984). The latter reported that only 11 out of 18 physics honours graduates, training to be physics and science teachers in a postgraduate certificate of education course, could explain electric current in terms of the conservation of current. Later, Shipstone et al (1987, reported in von Rhoneck and Grob, 1988) described the more prominent learning difficulties in basic electricity for 1250 grade ten students from five European countries. With only very minor national differences in results (despite different teaching methods), these students:

1. Considered that current is consumed even after instruction.
2. Used "local reasoning" in which current is said to divide into two equal parts at every junction in a circuit.
3. Used "sequential reasoning" by regarding a circuit in terms of **before** and **after**; the students reason that current in a certain bulb is influenced by changes before it comes to the bulb but a change after the bulb will leave the current in that bulb unchanged.
4. Did not differentiate the notions of current and voltage (except French students).
5. Expected a larger resistor to increase the current.
6. Introduced a compensation effect in which the battery supplied a constant current so that a change in one line of a pair of parallel resistors was reciprocally compensated in the other line.

Five learners from a small group of ten gifted students in grade nine, after having been taught electricity for one year, were reported to have developed a correct representation of electric current, whereas the other five formed an integrated representation incorporating several incorrect reasonings which are frequently found in students. Outcomes such as this with elite learners under research conditions would tend to confirm teachers' statements that the topic is intractable for learners aged 11 to 15 years.

Research Approaches and Issues

The difficulties in teaching and learning electrical concepts has attracted research interest because improving learning of these concepts is seen both as a challenge to learning theories and as a foundation for technological studies, like electronics. Researchers from the alternative frameworks field (through the work of Tiberghien and Delacote, 1976; Osborne, 1981a; Steinberg, 1983; Shipstone, 1985; Shipstone and Gunstone (1985) particularly), a group of problem-solving researchers (for example, Reif, 1983, and Larkin et al, 1980), and some cognitive scientists with an interest in analogy (for example, Gentner and Gentner, 1983; Tenney and Gentner, 1985), as well as curriculum investigators (van Aalst, 1979, 1985) and evaluators (Gott, 1985a, 1985b), have examined problems in learning electricity. Their combined ideas can be formulated as five issues.

Issues about purposes. The topic of electricity is thought to have been made more complicated than it need be by unfortunate teaching approaches (van Aalst, 1985). His alternative is for teaching to be adaptive rather than selective; then the approach would be less aimed at failing those learners who have not reached some arbitrary standard and more aimed at obviating the causes of failure, by better teaching, and by teaching useful knowledge (van Aalst, 1979).

An issue about problem solving. Gott (1985a, 1985b) has suggested that a quantitative approach to Kirchoff's laws should be put aside initially, in favour of a qualitative approach. One way of achieving this, he suggests, is to provide instruction in how to make circuits, which could precede the demand to explain their operation, thus meeting the needs of the majority who would be unlikely to be called upon to provide scientific explanations. Gott's results from a massive survey of 15-year-old learners, conducted in the Assessment of Performance Unit of the Department of Education and Science in Britain, showed a contrast in outcome if learners recognised a familiar context for problems they were asked to solve. For example, when learners were asked to solve problems using meters and circuit diagrams, a success rate of about 20% was achieved; if the problems involved solving a practical problem based on the same points, such as wiring a light in a caravan, about 60% were successful.

Issues about the curriculum sequence. Electric current might be more readily understood if the treatment of serial and parallel connections of resistors could be learned separately. According to van Aalst (1985) and Gott (1985a, 1985b) the series case causes the greater conceptual difficulty, because it is not readily resolvable by the linear-sequential reasoning (noted above) that Shipstone (1985, 1987) reported as the dominant mode in learners' reasoning. Domestic circuits (being parallel arrangements of resistors), might then be used to develop explanations for parallel circuits first, with series circuits being introduced a year or so later (van Aalst, 1985).

Issues about reasoning patterns. If sequential reasoning in explaining electric circuits leads to fallacious conclusions (as indicated by Shipstone, 1985, 1987), then this could be contrasted with a systems approach in which circuits are treated as reactive systems rather than linear. In order to achieve this change Shipstone (1985) suggested that adequate teaching and learning time and effort must be given to these topics, foregoing a tendency to move on quickly from simpler to more complicated circuits, and that classroom investigations with learners as young as 12 and 13 years need to be conducted. Little has been reported on how to develop systems reasoning when learning about electric circuits.

Issues about teaching. While it has been generally agreed that learning about electric current and its associated concepts is not easy, few have been prepared to state that the fault lies with inadequate teaching. Van Aalst (1985) though, considered that a concept-application model of teaching (corresponding to Renner's (1982) theory A), which may be effective with experts in their learning, may not be as effective with novices. He contended that *young people do not learn concepts, they learn how to deal with certain situations,* i.e. learning is context dependent. In criticizing the research on understanding electricity for its base in an expert-model of learning, van Aalst commented that

> *virtually no results can be found about contextual factors which determine cases in which pupils could resolve problems correctly. The research reports that not all students are experts, but it does not report what they can do nevertheless.*

The points about a qualitative approach based on practical problems, in which a new reasoning pattern might be established, will be used in Part 3 of this chapter, where another approach is to be proposed.

Research on Problem Solving in Physics

Novices cope with problems about light bulbs of 25W and 100W in series, similar to that reported by Armstrong (1985), by searching for a rule, formula or algorithm from which an answer can be derived algebraically (Reif, 1983). Thus they avoid interacting with the physical reality of the problem. In contrast, research into information processing and problem solving indicate that experts engage in a qualitative reasoning process initially. In this, their own reformulations or paraphrasings of a problem are allowed to interact with their common sense (Reif, 1983). In terms of the generative learning theory, a process of analysis occurs in which the common sense of these experts (the sum of their previously constructed and subsumed meanings coupled to their capability in using those meanings) is brought to bear on the problem. If the novice lacks these cognitive insights, and the confidence that arises from having used them successfully, and if qualitative reasoning does not occur, the mathematically-derived answers cannot be checked against common sense. Thus, the novice has no internal checks for accuracy, veracity or reality.

Research on the Use of Analogy

An approach which might circumvent some of the reported difficulties, and which will be used in this thesis, may be found in encouraging learners to create and define analogies. Scientists construct analogical models to deal with unobservable events. An important aspect of the instrumentalist view of science advocated in this thesis is the refinement of models by empirical and logical tests.

The fluid analogy in electricity. The model which dominates the present paradigm for the study of electricity was established by Benjamin Franklin and his successors as they reconciled the effects of attraction and repulsion with ideas of conduction. The model treats electricity as if it is a fluid that flows through conductors (Kuhn, 1970). As in other aspects of natural philosophy, the theory of fluids was essential in the early stages of theory formation (Hankins, 1975). Consequently, there has been a long tradition of using fluid-flow analogies in teaching electric current, particularly where the fluid is water, but there are few empirical studies which identify the benefits of this analogy for understanding electric current.

A new analogy for electric current. In contrast to the more common water-flow analogy, a second set of analogies based upon a flow of particles has been devised. Here the current corresponds to the rate at which a number of particles are pushed (Gentner and Gentner, 1983).

Positive aspects of these analogies. Both analogies provide an important source of insight and inference (Gentner and Gentner, 1983; Tenney and Gentner, 1985). Following Hesse (1963), these analogies can be examined for their positive (and as well their negative and neutral) relationship with the physical event.

The current-energy relationship is explained well by both; the faster the flow, the brighter the bulb glows. The water analogy has long been thought by physicists to be more effective in gaining an understanding of batteries (being analogous to reservoirs). The moving particles analogy is thought to be strained by this point. Both analogies account for resistance satisfactorily; viewing resistance as the rate of transfer of fuel to the bulb in the moving particle analogy, and as the degree of friction, or frictional resistance, in the flowing water analogy. The moving particles analogy has been shown to have attractive features for novices because it is concrete (Gentner and Gentner, 1983). In terms of schema theory, the source domain (particles moving) and the target domain (charges flowing) are closely aligned.

Pedagogical problems with these analogies. For young learners fluid analogies have several problems which have yet to be resolved. The most important one, described by Schwedes (1985), is the inaccessibility of the science of hydraulics. She has attempted to bring about intimate understanding of flowing water systems through the use of mechanical models. A second problem, in the opinion of several writers (Schwedes, 1985; Gentner and Gentner, 1983; Osborne, 1983b; Gauld, 1986; Shipstone, 1985, 1987; Shipstone and Gunstone, 1985; 1987), is that learners have a generalised or undifferentiated cluster of ideas about flow, rates of movement and related physical variables. As a consequence, the notions of current, voltage, resistance, velocity, power, pressure and force are interchangeably used. A major aim of this study is to establish conditions within which it might be possible to distinguish the ideas of current, voltage and resistance (1).

Learners' Intuitive Knowledge of Electricity

In addition to the many pedagogical issues just described, the "alternative frameworks" movement has opened up a sub-culture of prior concepts believed to have crucial influence on subsequent learning (Gilbert, Osborne and Fensham, 1982). The research evidence from alternative frameworks studies points to the conclusion that from an early age people develop their own explanations for electricity (Osborne, 1981a; Tiberghien and Delacote, 1976). Some of these explanations have been uncovered. These are often anthropomorphic or teleological, corresponding to Claxton's "gut science". An example which arose from another study by the writer (Cosgrove, 1983), came during a discussion with a boy (age 6 years) who was reading an electricity book in class. The boy described to the writer the operation of a torch circuit in terms of the bulb containing a small insect. He described its head, a small green ceramic bead, with two feelers or antennae protruding. This insect was fed from the battery and it produced light as its two feelers moved together and collided, so that a constant stream of sparks was formed. He explained the expiration of the bulb as the insect dying. The transcript of this interview is in Appendix 3.3.

This account can be interpreted as a sustained effort by that child to make a theory which accounted for electricity in terms of his knowledge of insect anatomy, life and death, food, and light-producing interactions (as when certain clouds are said to produce lightning when they touch).

The explanations for electricity held by older learners have been the subject of several reports, and these will be presented in two sets. The first summarises the views of school-age learners, and the second those of college-age learners.

School learners' views on electricity. The views of learners, from 11 to 17 years, have been examined by Osborne (1981a, 1981b). Using an "interview about instances" approach (Osborne and Gilbert, 1980), Osborne reported young people's theories as being in one of three categories:

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(1) The terms "electric current" and "electricity" are used interchangeably by many learners, and some teachers. If the latter term is used in this study, it means "an undifferentiated term about electrical phenomena", whereas the former term is used precisely when discussing the flow of charges in a circuit.

1. A uni-polar view, in which electric current gets used up in the bulb; Tiberghien and Delacote (1976) had earlier reported this theory.
2. A bi-polar view, in which two currents clash (1).
3. A scientific view, in which electric current goes around the circuit.

This last view was later differentiated (Osborne 1983b) into two circulating views. In one the current is partly used up in the light bulb; thus it is not conserved. In the other, all of the current is returned to the battery; the current is conserved.

A fifth model for current in simple D.C. circuits has been detected in the present study. In it, separate currents are considered to leave each battery terminal and travel around the circuit to the other terminal; there is both a positive and a negative current. This model is treated here as a version of the bi-polar view.

Idiosyncratic views. There are further views which individuals propose but which are not found generally. Such idiosyncratic views (e.g. that the wires in a circuit contain heat) have not been studied as part of this research.

The views of College-level learners. Steinberg (1983, 1985) investigated the views on electric current of U.S. College-level physics students. He started from the observation that students recognised that the terminals of cells were functionally different. His interviews provided three simple models consistent with this difference: a sink model (in which electric current is non-circulating and not conserved), a catcher model (in which electric current circulates but is not conserved), and a friction model (in which current is circulating and conserved).

The relationship between Osborne's and Steinberg's models. There is considerable similarity between these two sets of models. For all but the first of Osborne's models, Steinberg has described an exact counterpart. This first model, called a uni-polar view by Osborne (1981a) and model A in this study, has the electricity travelling from the cell or battery in one wire only. The second wire is required but it does not convey electricity back to the cell. This model was not represented in the views of Steinberg's College-level sample.

In Osborne's bi-polar view (model B here), a stream of electricity is considered to leave from each end of the cell or battery and each of these streams clashes in the bulb thereby making light and heat. In Steinberg's sink model, the electricity is used up, lost, or "down the sink". Osborne's circulating-but-not-conserved model for electricity, called model C, is identical with Steinberg's catcher model, in which a portion of the electricity is used-up, or caught, by the bulb. Osborne's circulating-and-conserved model is identical with Steinberg's friction model; in these models the current before and after the bulb is the same. This is called model D in this study. These models, A, B, C and D, are presented diagrammatically in Figure 3.1.

(1) A bi-polar view was once highly regarded, for Andre Ampere stated that *two electricities are carried in such a way that there results a double current, one of positive electricity, the other of negative electricity, starting out in opposite senses from the point where the electromotive action arises, and going out to re-unite in the parts of the circuit remote from these points...it is this state of electricity in a series of electromotive and conducting bodies which I name for brevity electric current.*

(Hurd and Kipling, 1958, p.221).

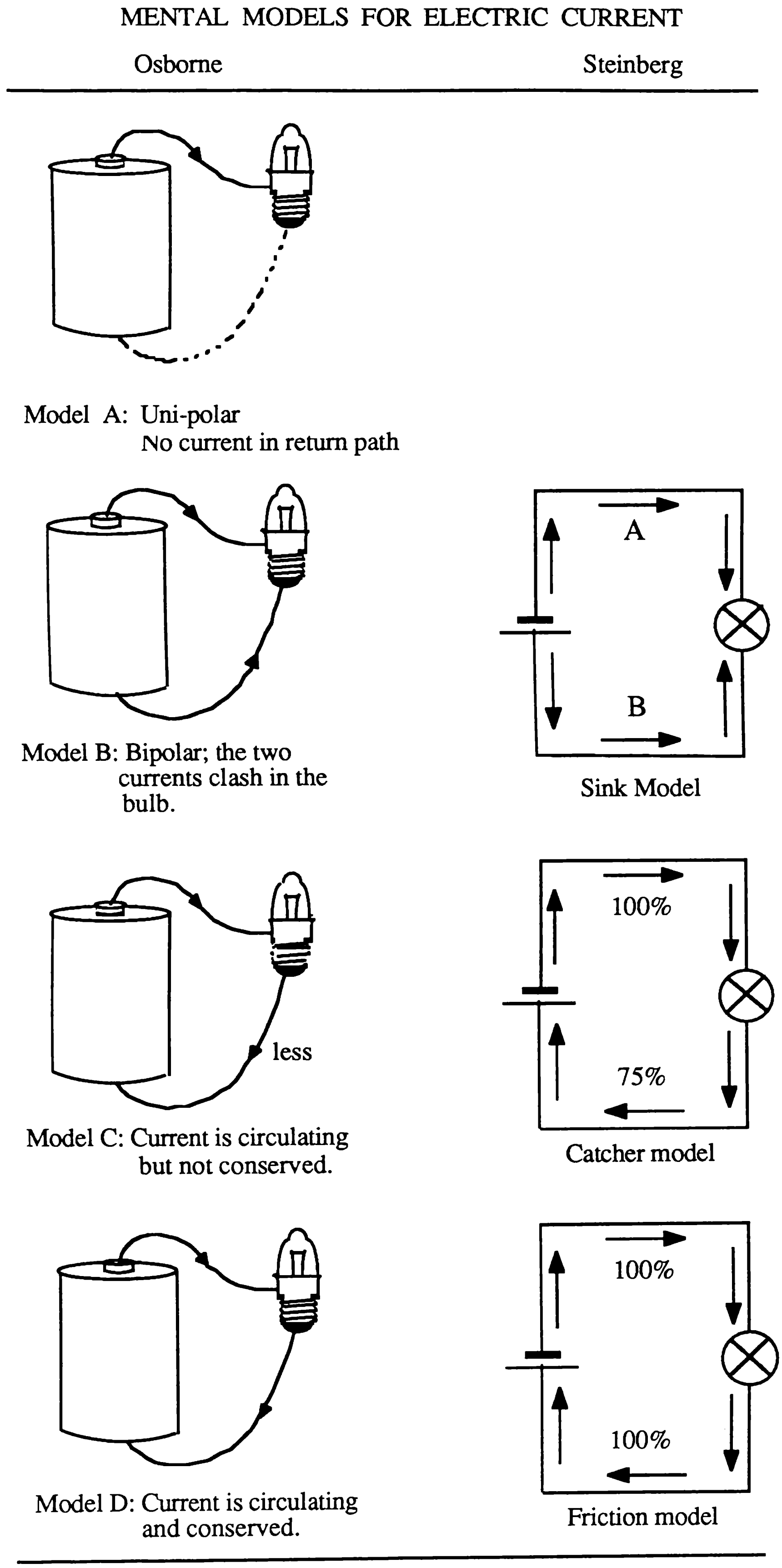


Figure 3.1: Osborne and Steinberg electric current models.

The similarity between these two sets of models, which has been explained above, provides researchers with a degree of confidence that they do in fact represent the important views young people generate to deal with electric current. However, there have been some reports of learners using different views in different situations.

Consistency of use of learners' views. Osborne (1983b) claimed that people he interviewed responded consistently when asked about their ideas on the simplest of D.C. circuits. Others have reported that responses vary according to the circuits and their contexts. Karrqvist (1985) has begun an investigation into the stability of the ideas used by one 15-year-old boy when he was presented with 31 different situations involving electric current. She noted that her subject used different models in different situations, and six different conceptual models were recognised.

In examining the models which 232 learners (ages 11 - 18 years) used in explaining circuits that were a little more complicated than the simplest ones, Shipstone (1985) also noted that some subjects used different models in different explanations.

The position adopted in the present study is that, for the simplest circuits, containing one or two bulbs, one battery, and the necessary wires, learners can recognise one of the Osborne models (Figure 3.1) as describing their own thoughts on the simplest circuits. This does not preclude there being times when learners will use other models, or when they will synthesise a model from an overlap of two Osborne-like models.

The Approach to Learning Electric Current Developed Here

Preliminary Comments

Science teachers and researchers have been described as being too concerned with presenting formal physics in a highly abstract form too early in learners' encounters with concepts. Papert (1980) considers that too little attention has been paid to developing learner-sensitive approaches.

> *It seems to be nobody's business to think in a fundamental way about science in relation to the way people think and learn it. Although lip service has been paid to the importance of science and society, the underlying methodology is like that of traditional education: one of delivering elements of ready-made science to a special audience. The concept of a serious enterprise of making science for the people is quite alien.(p.188)*

This admonition can be seen to favour the development of stepping stones, or transitional structures. In addition to this, representatives of the major research groups have agreed that

> *One of the most urgent challenges to researchers in the field of students' alternative frameworks and problem solving procedures is to develop teaching strategies which take research results into consideration and indeed lead to better learning.*
>
> (Duit, 1985)

Issues. The specific issues dealt with in this new approach are summarised below.

1. The ideas of Gott (1985a, 1985b) and van Aalst (1979, 1985) are combined to provide an adaptive, problem-solving approach, based on real-world problems of significance to the learners.
2. Analogy exploration is to be encouraged as a way of developing a non-linear, non-sequential reasoning strategy.
3. The issue of readiness is to be met in two ways:

   (a) The learning of this topic is not to be delayed. It is thought that the ideas which learners bring to science lessons should be examined at an early stage, and not delayed until their mathematical skills can cope with a quantitative approach. This approach will, consequently, be qualitative.

   (b) A learning environment will be provided in which learners will not be forced to conform to a prescribed learning regime driven by a tight timetable.

These points will be embedded in a teaching strategy which sets out to encourage cognitive development and at the same time to promote an instrumentalist view of science, with its problematic and investigative aspects prominent. The learning situations will be selected from the real-world technology that the learners know, and the technological metier of inventing (an idea or an object) and then improving it will underpin the learning process.

Deciding on Current

This investigation could be approached in any one of a number of ways, including beginning with voltage (Cohen, 1985; von Rhoneck, 1985), or by considering circuits as complete systems (Hartel, 1985). The entry favoured in this study is through current rather than voltage and resistance (Cosgrove, Osborne and Carr, 1985a, 1985b; Shipstone, 1985).
While it was known that learners generally wish to find out about batteries first, the advice of physicists, researchers and teachers was that clarification of learners' concepts of current would be more fruitful and less intractable than the electrochemical concepts needed to understand batteries.

A Physics Framework for this Study

A qualitative statement of Kirchoff's laws is required for the physics framework of this strategy. This will be based on Evans' (1978) description of current phenomena and Kirchoff's laws. Evans began by postulating that 'the greater the current flow through a lamp, the brighter it will glow.'
From this, four experimentally verifiable rules can be established:

1. The flow is not used up.
2. The size of the flow is determined by the size of the obstacle.
3. Two obstacles in series are a larger obstacle than either obstacle alone.
4. Two obstacles in parallel are smaller obstacle than either obstacle alone.

These qualitative rules will be incorporated into a set of simple circuit experiences based on real world situations (1).

Dealing with Energy in Electric Circuits

The concept of energy is not explored in this approach because the physicist's view is based on concepts not developed in the school curriculum until some years later. Physicists base their picture of energy in electrical circuits upon Faraday's and Maxwell's concepts of electrical and magnetic fields in which work is done by the battery on the bulb (Farwig, 1985).

Learners deal conceptually with electricity before the notions of work and force fields are developed in the curriculum, and before the mathematical operations for analysing these fields are introduced. If teachers are not to delay the teaching of electric current then an alternative approach is needed. The task is to find an honest way of presenting, or leading to, the physicists' ideas.

Teachers may have to resort to a less abstract notion in which energy is akin to a fuel; the concept of a fuel-stock becoming depleted is not outside young learners' experience. The problem is in finding out if the fuel-notion can be modified or built on later.

Conclusion

The research evidence confirms teachers' views that attempting to clarify electrical concepts is a daunting task. This study addresses the problem by finding out learners' ideas, by considering what learners can do, and the contexts most effective for learning. Further decisions included introducing qualitative ideas before quantitative, and setting aside the physicist's view of electricity initially. Differentiating current from voltage was planned to take place in steps involving learners in the elucidation, evaluation and re-construction of their own mental models. The resulting teaching package will be described in the next chapter.

(1) It is important that this be seen as a postulate and not an empirically verifiable fact: the typical school experiment of exploring the relationship between current and voltage is monitored by a piece of equipment which is constructed on the belief that the Ohmic relationship is true (for its components). So all that is achieved in the school experiment is a confirmation that the ammeter is behaving as it was designed to do.

Chapter 4

FORMULATING RESEARCH QUESTIONS DESIGNING A SCIENCE TEACHING UNIT WITH A TECHNOLOGICAL FLAVOUR AND DECIDING UPON A RESEARCH STRATEGY

Part 1: The Research Questions

The principal thesis, that science can be learned in a technological context, and the sub-thesis, that different views on learning are needed for this, have been addressed through three sets of research questions arising from the corresponding, preceding chapters.

Set 1: Chapter 1. Questions about technology.
These questions are based on implications of the view taken about technology.

Question 1. What is a suitable technological context for learning about electric current?

Question 2. What criteria can help in establishing technological contexts?

Question 3. Does the problem-solving orientation of technology provide the desired environment in which to learn this concept?

Question 4. Does this approach provide an understanding of the relationship between science and technology?

Set 2: Chapter 2. Questions about learning and teaching science.

Question 5. Is the generation of analogies by learners, and the consideration of others' analogies, an effective learning strategy?

Question 6. Do transitional frameworks assist learning electric current?

Question 7. Can the learning needs of females (believed to have been disadvantaged in learning physics) be met?

Question 8. Does this approach provide learners with an understanding of the nature of science?

Set 3: Chapter 3. Questions about teaching and learning based upon a summary of research on electric current.

Question 9. Is this approach accessible to teachers?

Question 10. What does this study say about curriculum design?

Question 11. Does this approach shed light on what learners **can** do?

Question 12. Is there a place for qualitative reasoning in learning electricity?

Next, the package which was developed for classroom trials to answer these research questions will be described, together with strategies used by the teacher to develop the learning environment, followed by the research methods used, and an overview of the data so obtained.

Part 2: Designing the Teaching Package

Establishing a Technological Learning Environment

The intention was to develop a technological learning environment which was illustrative of constructivist-developmentalist views of science learning as proposed, inter alia, by Barnes (1976), Papert (1980, 1986), Renner (1982), Musgrave (1982), Osborne (1985), and Faire and Cosgrove (1988).

Requirements. These views, and the theory of teaching and learning outlined in Chapter 2, required the classroom environment to be:

1. Relaxed and rewarding, and not coercive, so that the learners would want to take part.
2. A simulation of the ways scientists might go about the generation of new ideas, thus exemplifying the views of science adopted (Chapter 2).
3. Empowering learners to explore their own ideas with a view to modifying them if required. While the scientist's idea was not avoided, it would not have undue prominence.
4. Challenging when the worth of new ideas was being tested, and in the model-building stages.

Designing the teaching unit. The teaching unit was designed with three phases, corresponding to the three parts of the generative teaching model outlined in chapter 2. The specific activities described here were developed initially for learners of 10 to 12 years (Appendix 4.1).

The Familiarisation Phase

Steps. Learners would be provided with many simple experiences of electric circuits, using one or two cells (1.5 V), one or two identical lamps (rated at 70 mA at 1.5V), a double-pole switch, and multi-strand, low current wire.

There were seven steps in the familiarisation phase.

1. A safety session. The teacher would introduce the equipment and describe its safe use. During this time learners' ideas would be uncovered and explored as the learners talked about their knowledge of electricity.
2. Making a bulb glow. The learners would be able to display the levels of their prior knowledge and skills.

3. Sending messages in Morse Code using this equipment. This was designed to retain the interest of the more experienced learners, while those less experienced were provided with time to increase their confidence and competence.
4. Extending simple Morse Code signalling devices. By adding more bulbs, batteries and switches, learners would make more complex circuits.
5. Devising methods for recording circuits using drawings, stories and symbols.
6. Constructing nine selected circuits. Embedded in each was a point of interest or an effect designed to be thought provoking, puzzling (when learners' theories were formulated and tested later), or an illustration of a technological system.
7. Consolidating knowledge. The learners' ideas and explanations for various effects, and in particular what they considered to be happening in the wires in circuits, would be sought.

These activities of the familiarisation phase were designed to ensure that learners had frequent contact with the conceptually important experiences of serial and parallel combinations of one, two and three bulbs, and of one, two and three cells.

<u>The teacher's role.</u> Throughout the familiarisation phase, the teacher's role was seen as

1. promoting the flow of ideas and knowledge which learners brought with them,
2. assessing the readiness levels of all learners,
3. extending the already competent learners while providing the time in which novice learners could build up a body of experiences,
4. challenging learners to improve circuits they had invented,
5. helping learners to devise codes for communicating circuits as stepping stones to the introduction of the electrical code,
6. promoting linkage of these circuits to real-world situations,
7. helping learners to summarise their ideas about circulation, batteries expiring, the various states of brightness in the bulbs, and how light might be produced at the filament.

<u>Teaching strategies.</u> Throughout this phase, the teacher's main role would be in questioning learners about their explanations. This would start with broad questions which would gradually become more sharply-focussed. An example of the former type of question, when a group had two dimly-lit bulbs in series with one cell, would be *What do you think is happening here*? Later a question such as *What do you think is happening in this wire, or that wire?* would become the focus. The teacher would try to avoid giving direct answers to learners' questions, by deflecting questions back to the asker. If, for example, a learner was to ask *Why does the filament glow?* the teacher would respond *Tell me how you think about that.* The learners would become less dependent on the teacher for information, as they would know that they would be expected to think for themselves.

The Challenge Phase

A critical experiment. The teacher would judge when the learners were ready to declare their views about current in a circuit. From individual statements, a class summary would be prepared. Next the teacher would introduce Osborne's four models for electric current and link these to the class members' ideas. Learners would debate the merits of each and suggest further models. The debate would continue until a critical experiment was designed by the learners to resolve the conflict presented by the alternative models. This experiment would enable learners to 'see inside the wires' in order to discriminate amongst the possibilities suggested by models A,B,C and D.

Analogy. Analogical systems familiar to the learners would be introduced to deal with the result of the critical experiment. For example, the operation of ammeters would be compared with the way traffic engineers record the flow of vehicles by placing across a road a black rubber tube connected to a recording device. Further analogies would be developed from learners' ideas in their efforts to make sense of the outcome of that critical experiment.

The Application Phase

A set of practical problems was chosen for their interest, accessibility and attention-gaining capacity for these learners. Here the purpose was to assist the integration of new ideas about electric current with existing ideas by engaging in an extensive constructionist process (Papert, 1986). This was attempted by giving prominence to real world events and situations.

The technological problems.

1. Christmas tree lights. Learners would propose solutions to the problem that arose if one or more bulbs failed, all bulbs failed to glow.
2. Railway tunnel. Learners would decide how the presence of a train in a tunnel could be monitored by an electric current.
3. Traffic lights. The main problem was to work out how to switch the current in each of three ways so that the red, amber or green bulbs were individually activated. Then three more bulbs would be introduced, so that a road intersection was simulated. Some learners would try to work out how to colour the bulbs so that they emitted red, green, or amber light.
4. A binary call code. Learners would use binary arithmetic to work out how many bulbs would be needed for each person in the class to have her or his own binary number.
5. Car heater switches. Learners would simulate the circuitry controlling a car heater through both its own on-off switch, the over-riding ignition switch, and ways of altering the rate at which a fan could blow.

6. A lighting system for a mine. A lighting system would be designed with a line of four bulbs such that when any one was turned on, the others were turned off in a single action.
7. Car indicator lights. Learners would design and make a circuit which simulated a car indicator lights circuit, then seek ways to interrupt the current so that the lights flashed.
8. A visitor at the door. First, learners would model the circuit used in some houses whereby a push-in switch activated a door-bell. Then they would find ways to indicate at which door, the front or the rear, the switch had been pushed. They would then devise a way whereby a deaf person could be informed of a visitor's presence at the front or rear door.
9. An electric motor. The problem was to increase or reduce the rate of rotation of a small electric motor, by altering the flow of charge from a battery. Then a switch would be devised to change the direction of rotation of the motor.

These technological problems were designed to encourage a progression from trial and error problem solving approaches to systematic strategies in which the solutions proposed for the earlier problems would be used in the later problems. In this way learners would build up a body of knowledge useful for solving circuit problems and in understanding electrical phenomena.

The problems were from the real world, and some technological principles such as feedback, control and modularity were illustrated in their solutions. Rarely would there be a single right answer, nor would there be any books containing answers. In solving these problems learners would experience the technologically significant notion of optimising (by establishing an answer and then improving it) as they produce and then evaluate their own answers.

This Teaching Unit and the School Syllabus

The teaching unit described dealt with the electricity topics of Forms 1 to 4 school syllabuses (such as current, voltage, resistance, thermal effects) as listed in chapter 3. It omitted electrostatics, and electrochemistry, i.e. electrolysis and electro-plating. Evidence from another study (Cosgrove and Osborne, 1981) suggested that teaching electrostatics and electrolysis in close proximity to initial programmes in chemistry caused much confusion in learning chemistry.

The next section contains a description of the methods used to describe the teaching and learning that occurred when this package was used.

Part 3: Research Methodology

This research set out to **describe** the effects of this teaching package in classrooms. At the beginning of the study, after discussions with a number of science education researchers (White, 1982; Osborne, 1982a), it was agreed that the following methods would be used.

Methods Adopted

Descriptive educational research has become an acceptable way of proceeding when attempting to understand aspects of learning (LeCompte and Goetz, 1982) provided that the account given is true, simple, and minimally distorted by the researcher's ideology. To offset criticisms associated with non-statistical research (Rein, 1978) and to aid researchers who adopt these approaches reporting their work, Erickson (1986) and Smith (1987) have proposed that empirical assertions, narrative vignettes, quotations from observational field notes and interviews, interpretative commentary and theoretical discussion be the framework. These will be approached in this study through the following descriptions.

Observations. Classroom observations and descriptions would be made by the researcher, teachers and experienced observers.

Clinical interviews. Certain learners would be asked about their understandings of key ideas prior to, during, and after a learning episode. Interview protocols followed the guidelines summarised by Bell and Osborne (1981), and Osborne (1985).

General interviews.

(a) Specific learners would be interviewed to obtain their views about the learning experiences and their views of how their understandings have been influenced by the learning episodes.

(b) Teachers would be asked about their views of the prescribed, intended and actual instruction received by the learners, together with their views of the impact of this instruction on learners' ideas.

Surveys. Groups of learners and whole classes would be surveyed to ascertain understandings at various stages in the learning process. Several surveys were designed, including a ten-question survey to find learners' views of the subject matter parts of the teaching unit for use mainly in secondary schools (Appendix 4.2). Most of the questions in this survey ask learners to select an answer from a set of proposed answers and then to say why they think the answer they have selected is the best one.

Methods not used. Questionnaires, a conventional information-gathering strategy, were not used in this investigation because of the restrictions they place on exploration of a respondent's perceptions and conceptions. They are closed and selective, with the selection being made by the researcher, so they could be regarded by respondents as a vehicle to present the researcher with an expected answer (as perceived by the respondent) rather than with the respondent's own perceptions and conceptions. They can produce spurious results;

for example, when respondents select a response from a set of alternatives, the researcher cannot tell if the answer was based upon sound reasoning or on a guess. Thus right answers might be based on wrong reasons, while the researcher must accept that a right answer is based upon a right reason. This problem has been described by Gauld and Ryan (1983) as a potential defect in questionnaire-based investigation. As well, it is difficult to follow up points of interest if questionnaires are analysed some time after being recorded. (This difficulty applies to written surveys, again if they are examined some time later).

Comparisons. Direct comparisons between the learning which occurs in these classes and conventional outcomes were not made, for three reasons:

1. Little was known of the effects of constructivist science learning episodes so the principal purpose was to describe the learning which did take place.
2. If the evidence produced by Shipstone (1984, 1987) is typical, and teachers' opinions would say that it is, then the present method of teaching electricity topics is singularly unsuccessful. So the task is to find an alternative way of enabling learners to understand electrical concepts.
3. In a real classroom it is not possible to control all the variables needed for a comparative study.

The aim. In answering the research questions, the aim was to devise an adequate way of arriving at a description which could provide insights

1. on why this package produced, or failed to produce, the desired outcomes.
2. which can be used to improve the package.
3. which will enable teachers and curriculum designers to make informed decisions about whether to try the strategy in classrooms, namely;
   (a) did it result in effective learning?
   (b) was the new strategy manageable, and satisfying to teach?

The Status of Qualitative or Ethnographic Research in Science Education

The research community in science education enjoys a high degree of confidence from the way its methods have been accepted by both educational and scientific audiences. This confidence is based on convictions that matters of validity and reliability are achievable by a conscientious balancing of the various factors enhancing credibility within the context of (their) particular research problems and goals (LeCompte and Goetz, 1982). Riechard (1985) critically evaluated the methodologies reported in a related study (Osborne and Cosgrove, 1983), commenting that this approach

> *makes a conceptual contribution to research on what children know about natural phenomena, that it also makes a methodological contribution,*

and

> *that it represents a commendable effort toward blending of approaches which can strengthen validity and reliability.*

Potential Methodological Problems

The insights provided by qualitative approaches can convey a sense of what learners say and do within the experimental situation under study provided that certain hazards are negotiated. Erickson (1986) identified six potential methodological problems with qualitative research as

- inadequate negotiation of entry in the field setting
- limited researcher access to relevant data
- inadequate amount of data
- inadequate variety of data sources
- faulty interpretive status of evidence
- inadequate discrepant case analysis.

Each of these potential problems has been confronted in this study, as indicated next.

Negotiated entry. In this study the first of these concerns was dealt with by working with classes which had been offered by their teachers. Confidence was developed through prior contact with teachers (usually) and with learners (when possible) at their schools.

The need to promote confidence was recognised because there was a marked difference between the way this teaching would be presented and the conventional way science is taught. A careful approach was adopted because many teachers in primary and intermediate schools are reluctant to teach science at all and rarely feel comfortable in discussing it with perceived experts.

Access to data, and the amount of data. Trying to capture the interactions which occurred in discussions was no easy task. The presence of recording equipment, particularly video, was considered to be distracting or disturbing to some learners. These interactions do not allow for rehearsal or repetition and so could not be captured in a studio. Yet it was necessary to record them if an authentic version of events was to be described. So with low-level recording equipment, the services of observers, and the minimum of intervention the researcher attempted to report some of the significant classroom events occurring in classrooms with 30 or so active learners.

This research attempted to recognise learners' ideas at points where significant events were expected to take place. Because the research methods must be low in intervention it was not possible to capture non-verbal exchanges as these would have required video recordings, with concomitant distractions. Audio recordings of small groups of learners were attempted when they were engaged in self-directed investigation or debate, but often the recordings were indecipherable as much of the communication was unrecognisable by the researcher, being based upon non-verbal signals and a spoken language with little conventional structure or logic. While this may have been good for learning, it was not for researching. This, though, was just the situation Barnes (1976) promoted as a key aspect in establishing a climate in which learners generate their own meanings with the least intervention.

Variety of data sources. Information was gathered from learners directly, by interview, observation and through obtaining examples of their work. Further information came from teacher-observers, researchers who were colleagues and independent researchers.

Faulty interpretative status of evidence, and inadequate discrepant case analysis. By calling upon a number of observers (some of whom were collaborators and colleagues, others were independent) and through frequent discussions with them, as well as by other forms of peer-review through seminars and papers presented at symposiums, problems of bias would have been exposed and minimised.

Conclusion

In this investigation, decisions would have to be made about what information would be the most useful, after it had been decided what outcomes would be the most important. As the central focus would be on elucidating and modifying learners' understandings as the result of specified classroom experiences, then information would be required primarily on these experiences and their impact on learners' thinking.

The main task confronting the researcher was not merely to avoid bias, but to be selective, for the observation of a classroom, together with the verbal and written comments of teachers and learners, was likely to provide too much information.

Chapter 5

CLASSROOM TRIALS

Part 1: The First Trial, at an Intermediate School

Entry. This first teaching episode took place at an intermediate school where the researcher was known in his role in pre-service teacher education. The researcher was invited by the Principal to become involved in the school's science curriculum development. A class was chosen for this study by the Principal from those offered by their teachers.
The research programme. The researcher taught the class of 35 learners (ages 11 ± 1 years), for the familiarisation phase. A sample of 15 learners were then taught the challenge and application phases. Surveys and interviews were made during and after the teaching by the researcher and a colleague-observer (RJO) twice later; the first time being two months after the teaching concluded, the second being nine months after the teaching ended. Five learners from this group of 15 were interviewed by the researcher intermittently up to three years later. One learner was selected to be the subject of a small case-study.

The Teaching

The class was taught by the researcher in the familiarisation phase outlined in Chapter 4, with the regular teacher as observer. After eight lessons (of about 45 minutes each), a group of 15 was selected by the class teacher to continue to be taught by the researcher in the challenge phase. Information about some of this group is summarised in Appendix 5.1.
Learners' ideas. The challenge phase began with the 15 learners (listed in Table 5.3) being asked to say what their ideas on electric current were. Responses were tape-recorded and later transcribed. These ideas included:

> *A battery is made up of different chemicals which is contained in a round flat-shaped battery. The two wires are connected to the battery both of then sending equal amounts of power to the light, making it glow.* (learner 1)
> *An electric current comes from the battery through the wires to a smaller wire in the bulb which because it is so small it cannot handle the amount of power going through it, which makes it glow.* (learner 4)
> *I think a current is an acid which flows through the wire as an electric current. So when it enters the light it burns a piece of metal making it glow.* (learner 5)
> *An electric current is like a water tap, the water comes out of the tap and goes down the drain then it is cleaned and goes back to the tap. The wire is just like a pipe, it takes the water to and away from the house.* (learner 6)

The electricity is sent through the bulbs and then back to the battery by wires again. (learner 10)

The current models. After the teacher explained the four models, the learners were asked to comment on the ideas contained in each. Some of their comments were recorded:

On model A

There isn't a circuit. (learner 4)

You need to have a negative wire and a positive wire to make the circuit and make the bulb glow. (learner 3)

If all the power went into one bulb and no return input then the battery would flatten fast. (learner 2)

On model B

There isn't a circuit. (learners 4,6,7,8)

The power is getting drained into the bulb, the bulb could blow with too much energy. (learners 3, 12,13,14,15)

On model C

I like model C because it has a current that flows through a bulb weakening the current. (learner 5)

When the power goes into the bulb it might be consumed a little but I'm not sure. (learner 3)

In model C they take some power to the bulb through one wire and the waste product is taken through another wire back to the battery. (learner 1)

Model C is good because some electricity went to the bulb, some was used, and the left-over electricity came back to be re-used. (learner 14)

On model D

I dislike D because to power a bulb you need to use some power. (learner 5)

I wasn't sure about D. (learner 2)

D could be right but your battery would not go flat but batteries do go flat. (learner 10)

The learners did not ask to be told the right answer. When asked to select one of these models for its congruence with their view of electric current, these learners all supported model C. Their responses are summarised in Table 5.1.

Table 5.1: Learners' first selections of electric current models.

Model chosen	A	B	C	D
Number selecting	0	0*	15	0**

Key * Learner 2 considered that model B had some merit, but that model C was probably better.
** Learner 5,supported both models C and D, and he settled on model C.

The critical test. Next the teacher demonstrated equipment used to measure the current in each wire. The action of the meters was explained by analogy to traffic counters on streets, and the children were able to inspect and handle them. First the circuit was made with just one ammeter. The reading was noted. Before the second ammeter was installed the learners were asked to predict if the current shown by it would be the same, or if different, whether it would be more, or less. They observed that the two ammeters showed the same current (about 200 mA). The children expressed surprise and some were disappointed because they felt that they had made a wrong prediction.

Analogy and role play. The teacher suggested an analogy between the ammeters and traffic flow counters in which the meters were counting cars travelling along a road, not the number of passengers in them. A role play, in which learners carried fuel from the battery to the bulb, was enacted. The learners came to accept the result of the critical experiment, but were not convinced, as these comments indicated:

> *After the explanation model D is O.K.* (learner 3 and others)
>
> *I understand model D but I don't get it.* (learners 6 and 9)
>
> *I understand model D but I think it is right in terms of power not electrons.* (learner 7)
>
> *Now that it has been explained I still like model C because I am counting the energy.* (learner 14)
>
> *Model D is O.K. now it has been explained but I still like model C.* (learner 12)

Table 5.2 summarises the children's responses (obtained from a show of hands).

Table 5.2: Responses after the critical lesson.

Model chosen	A	B	C	D
Number selecting	0	0	2	13

The learners acknowledged the data from the critical test as puzzling information rather than as compelling evidence for one of the views. They retained their own ideas alongside the new idea. Some of these learners were noticed to be upset because they had made a rare mistake. Many of these learners did not expect to make mistakes, and their confidence was shaken.

The Technological Problems

The application phase outlined in chapter 4 was introduced. Learners sought solutions to circuit problems while the teacher-researcher attempted to deal with their uncertainty and consternation about the models by helping learners to interpret circuits in terms of the conservation of current.

The technological problems were investigated in hour-long sessions, weekly, for seven weeks. The learners worked in groups of their own choice, mostly with three or four people, but some worked alone. Exchanges between groups were encouraged by the teacher, usually after reviewing learners' reports on their solutions.

Learners were introduced to new materials and new techniques at suitable times: for example, in simulating a set of traffic lights, lights with coloured filters were provided. Since these lights did not fit the bulb holders, a soldered joint was needed and the learners working on this problem were trained to use a soldering iron. The introduction of new ideas or systems is consistent with problem-solving, providing the engagement to motivate further learning.

The teacher encouraged reflection on views of electric current by asking questions such as *Which model helped you to explain what you see happening in your circuit?* and *What would an ammeter indicate in this wire, and that wire?* Some examples of learners' solutions were noted.

The Christmas tree lights problem. The teacher-researcher noted that most learners were able to recognise that the problem could be solved by replacing a series arrangement with a parallel set-up (without using those specific terms). They reported that much more wire would be required, and that the battery would expire more quickly (which was tested and verified).

There were some unusual and highly-creative proposals. For example, one learner placed a switch across each bulb. If the bulbs failed to glow, then by closing the switches the current was allowed to by-pass the defective bulb. This solution is shown diagrammatically in Figure 5.1.

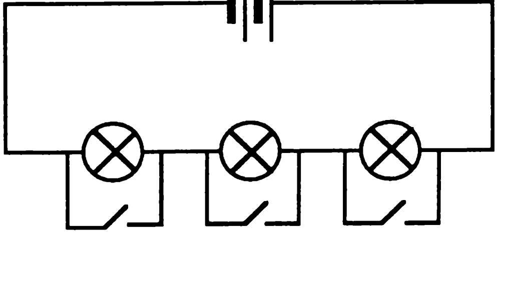


Figure 5.1: A novel solution to the Christmas tree lights problem.

The railway tunnel problem. Using parts from a model train set, learners devised a circuit which established the presence of a train on the railway lines. Most responded with a system like that in Figure 5.2.

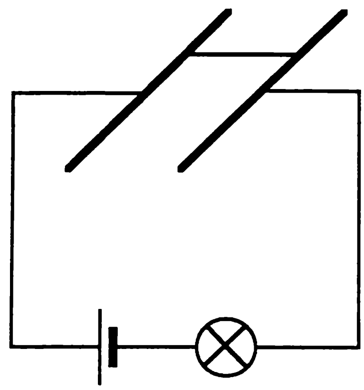


Figure 5.2: A typical first solution for the tunnel problem.

For some learners this was sufficient, and they moved to the next problem. But others quickly modified this solution because they found fault with it. They asked *How would you know if the train was in the tunnel or outside it?* and suggested that the rails in the tunnel would need to be isolated from those outside, as illustrated in figure 5.3, where two pairs of gaps represent the isolation of the tunnel rails from the outside.

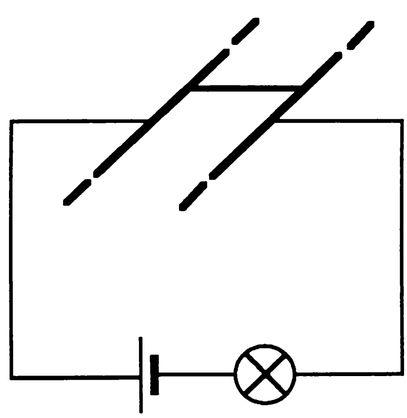


Figure 5.3: Isolating the tunnel rails.

Further improvements were then proposed and tested. For example, learners considered how to deal with the bulb failing. These learners used their result for the Christmas tree lights problem to place a second bulb in parallel with the first. This approach was extended by incorporating a back-up battery in parallel with the initial battery, and the combined set-up is shown diagrammatically in Figure 5.4.

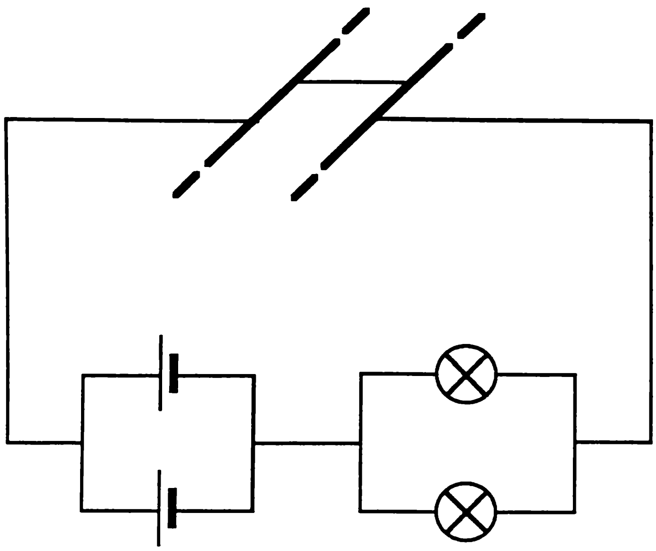


Figure 5.4: Further developments to the tunnel solution.

Some learners decided that each end of the tunnel would need to have its own indicator system. This circuit was put together about 20-25 minutes after the group had first confronted the problem. Soon after, the group said that they now did not think that any of these solutions would be effective, since a derailment in the tunnel would not be indicated. Some learners proposed that a television monitoring system might be more useful, particularly if each wagon was identified by a bar code which the camera could add to its memory on entry, and subtract on exit. If this adding and subtracting system did not balance after the passage of a train, then some part of the train must still be in the tunnel. Learners then decided to ask how the Railways Corporation kept a watch on its tunnels, and information was sought by writing to a Railways engineer.

Insightful solutions emerged. One learner brought to the class one week later another suggestion on how to deal with a possible battery failure. He wrote (original spelling):

> *I think if a train comes to a long tunnel and wants to know if another train is in the tunnel this is what I think they should do. Every train has an engin and an engin can generate electricity. So the train can generate + charge to the weels on one side of the train and - charge on the weels on other side of the train. Put rubber plugs at each end of every tunnel. Connect a light to the rails. So when the train crosess the rubber plugs the light will flash on at the other end.*

This imaginative and sophisticated proposal brought pleasure to its proposer, who was not highly regarded by his regular teacher for his previous learning. Some learners added their own practical problems such as *Does the light in a refrigerator stay on when the door is closed?* to those being explored. There was much co-operative learning and sharing of ideas. The learners were unwilling to leave when it was time to finish each session and they would have continued with these activities long after the seven-week session had concluded. Some did, and their efforts were presented in a regional science exhibition.

Individual Learner's Examples. Some of the learners developed these problems in response to their own ideas.

Ivan. The observer (RJO) noted that one boy, Ivan, had made a circuit unlike the others' so he asked Ivan about it. (Ivan's academic profile was low; it is summarised in appendix 5.1).

Observer	*What have you got there?*
Ivan	*An ambulance...I worked out something...*

The observer sketched the equipment that Ivan had put together (Figure 5.5).

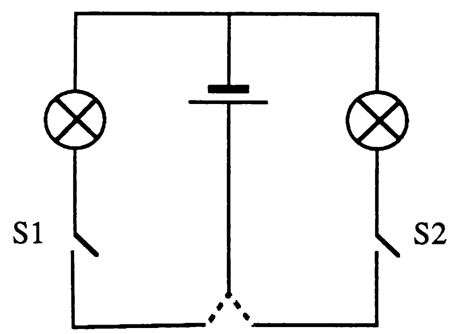


Figure 5.5: Ivan's circuit.

Ivan explained what he was trying to do.

Ivan	*See, if we switch it to there* [both S1 and S2 open] *both of them go off at the same time. Then if we switch that over to there* [closes S1 and the central switch] *then it goes like an ambulance.*

The observer noted that Ivan made the bulbs flash alternately as the central two-way switch was oscillated manually.

Craig. The observer (RJO) interviewed Craig two months after the teaching of this topic was completed. This extract from the transcript illustrates the technological approach of invention and improvement.

RJO	*What was the most complicated thing that you've made?*
Craig	*Solving the Xmas tree lights problem.*
RJO	*Uh-huh.*
Craig	*I used a lot of wires at first.*
RJO	*Yea.*
Craig	*When I first did it, then I found a simpler way to do it.*
RJO	*You did?*
Craig	*Yea.*
RJO	*Can you draw, can you remember how you did it? Can you draw it for me?*

Craig	*First we had the .... I can't remember what the lead one was. Then I found a simpler way....it was* (see drawing)
RJO	*So, did they all light up when you had it like that?*
Craig	*Yea. I'm sure that's the direct way.*
RJO	*So, when one went out, the other two kept going?*
Craig	*Yea.*
RJO	*I see. That's clever.*

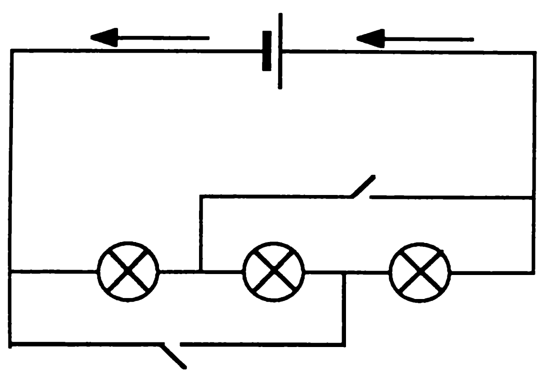


Figure 5.6: Craig's drawing.

In another part of the interview Craig indicated that he held a model B view (using the remembered result that the ammeters gave the same reading), yet he used a circulating idea in explaining his drawing.

Comment. If all that had been required was that Craig change his view to model D, then he has failed. But in providing an interesting solution and then simplifying it, he has displayed an effective problem-solving strategy. This strategy is at the heart of technology; he invented a solution, then he improved it.

Stephen's Solutions: A Case Study

Stephen, an 11-year-old learner, was a reserved youngster who usually worked on his own. He produced detailed solutions to two of the technological problems. He showed unusually quick insights to all of these problems, and was happy and not apprehensive when working on them. In problem four he was asked to link up four bulbs (simulating a circuit for the lights in a tunnel, or mine) so that a person, proceeding from one switch to the next, could throw that switch resulting in the first bulb being turned off and in the same action the second would be turned on. Stephen quickly constructed a system which did this. The observer (RJO) tape-recorded a discussion he had with Stephen. This part of the transcript indicates Stephen's grasp of the problem:

Stephen	*I think it was quite neat having bulbs, and switches, and batteries between two people and we could relate our ideas. Then we slowly got onto puzzles. And I think that was the best part.*
RJO	*What were some of the puzzles that you did?*
Stephen	*One of the best ones I think was the lighting system for the tunnel where you went through and you turned on a light and you went a little bit further and if you pulled a switch;the light behind you went off and the one in front of you went on.*
RJO	*Can you remember the circuit for that?*
Stephen	*Yes.*
RJO	*Could you draw it?*
Stephen	*Sure...it'll be a bit messy.*

A copy of Stephen's drawing is recorded in Figure 5.7.

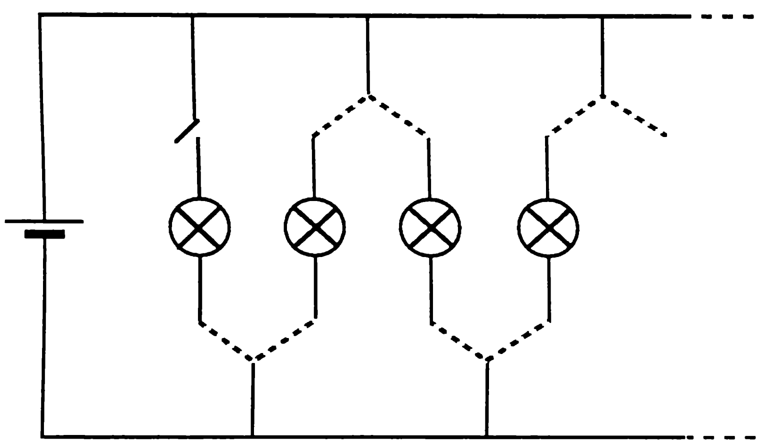


Figure 5.7: Stephen's solution to the mine-lights problem.

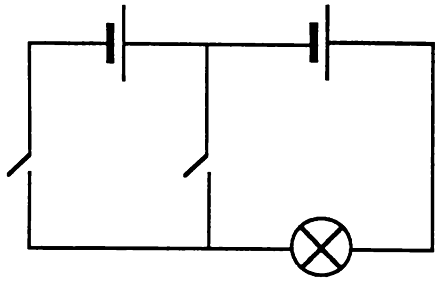
Then Stephen said

> *The point is, it does have disadvantages. I mean, if one person went in the same entrance twice it wouldn't work. That's about the only problem with it.*

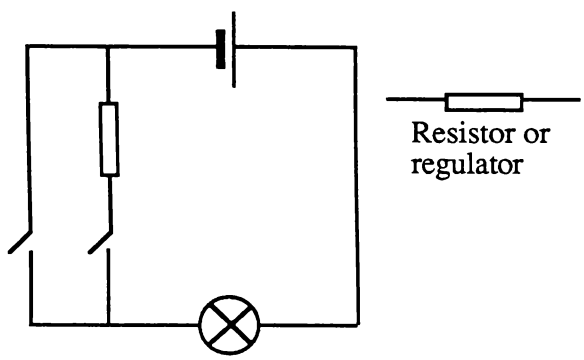
Stephen brought to class one day his solution for the problem of deciding, from the sound of a bell, which door a visitor would be at. He wrote:

The Puzzle of the Unmistakabells.

The puzzle starts off with a house with two front doors and a door bell fitted to each one. To show if one of the bells is ringing a single light goes on to indicate it. And the puzzle is how *to show which bell is ringing by using a single light bulb. My first answer was this circuit diagram*



If door-bell 1 was going (shown as the left switch in the above diagram) both batteries would make the light bulb glow brightly. But if door-bell 2 was going, only one battery would be powering the light bulb, making it rather dull.
Another way of doing this would be with this circuit, but with only one battery:



If door-bell 1 was going, then the battery would power the bulb, making it glow brightly. But if door-bell 2 was going, then the power would go through the resistor which would reduce the flow of electricity which would power the bulb. Therefore the bulb would be dull.

It might be thought that this learner had brought much prior knowledge to bear on this problem. However he had discovered the resistor idea in class by testing the stainless steel spring from his retractable ball-point pen in his circuits. He reported that it got hot when connected to a battery, and that he could dim the bulb with it. Stephen was challenged to find a solution to this problem with only one battery in the circuit.
A feature of Stephen's, and other learners', involvement in these problems was the enthusiasm conveyed when talking about them to observers, and when interviewed about them two years later. For Stephen and some others this teaching and learning incident provided a rare opportunity for success and this surprised the teacher. Stephen's teacher had told the observer:

> *When he's actually in class he isolates himself, he's diffident, he is negative towards other children...and they...are negative back. He's a vulnerable child,*

he gets hurt very easily. But he radiates when he comes to (science). And I've watched him very closely while he's been in the science room. It was good to be able to tell his mother that he had projected so well as there were things worrying her.

These reversals of behaviour from reluctant or recalcitrant learner to motivated and involved learner were achieved without any period of rehabilitation.

Comment. Stephen, like Ivan and Craig, was not enjoying learning before this teaching episode. Each presented their teacher with problems which she and the school's curriculum could not deal with. In this unit she acknowledged that they achieved rare success. At the same time the learners who usually did well were also successful, as shown in the interview segments that follow.

Interviews with Learners after the Teaching

One month after the teaching had concluded, and then five months after that, the researcher and the observer interviewed individually most of the 15 learners in order to elicit their selection of a model for electric current, their ideas about their selection and the previous models they had held, and their views on the worth of the technological problems. These interviews were tape recorded and later transcribed. A selection of extracts from the interviews is presented here to indicate the learners' reasoning, their views on their prior models and their feelings about changing their views.

Interview extract one.

Sylvia - one month later:

RJO — *Can you describe to me what you did from the beginning?*

Sylvia — *We started off with making the light bulb go. How to attach the wires. Then we started making more complex things; making three light bulbs go, and things like that. And making traffic lights so when the red went on, the green went off.*

RJO — *Oh, I see. And how did you find all that?*

Sylvia — *We just had to figure it out. And if we had troubles the teacher would come and he'd just give us ideas of how to do it.*

RJO — *Can you tell me one time which was the best time, and another time which was the worst time?*

Sylvia — *I think the best time was when we started to make the traffic lights. We were soldering some wires onto the little bulbs, the different coloured light bulbs. And then we put them into tubes and set them up so they'll work. That was quite good. The worst times were when we learned something, and the next week we'd just repeat it, and that was pretty boring. During the time when we had the whole* *class we kept going over what we'd learned, to get everything straight. But for people who had understood to start with, that wasn't too good.*

(The Interviewer asked Sylvia to make a bulb glow.)

RJO *Could you describe to me how the electric current would be going in those wires?*

Sylvia *Well, I'm not too sure about this, but I think there's a little thing, and it comes around and it drops off all its energy here, and feeds it to the light bulb. And it sort of goes like a little car, back up here, picks up some more, and keeps going around.*

RJO *So how would the current in here compare to the current in there in size?*

Sylvia *Well, they'd both stay the same. I mean, the electric current in here, the current would stay the same, because its sort of like little cars. Say you had two people, and you go down here. You have one car and you drop off one person, but you'd still have one car going back up here. So it'd be the same.*

Next the Interviewer described the electric current models as different people's ideas about electric current.

RJO *....How did you think about it before you had the lessons?*

Sylvia *Before... I thought it was either it came out both ends and clashered, clashed. or it came, a lot came and fed, and a little bit came back.*

RJO *I see. You thought it was either B or C. So what do you think now?*

Sylvia *I think its D.*

RJO *Are you happy with D now?*

Sylvia *Uh-ha. But I did prefer it when they clashed.*

(Later the Interviewer and Sylvia discussed the problem of learning about invisible things).

RJO *It's difficult to talk about this because you can't see it, or feel it, or touch it.*

Sylvia *It was good with the teacher because he gave a comparison. Like he said it was like little cars going over one of those things that measure how many cars go over. There may be six people in the car but the thing would only measure one car. And there could be only one person in the car but it would still measure* it.

A further five months later, without any prior warning or preparation, Sylvia was interviewed (using a similar protocol) by the researcher. Towards the end of this interview the researcher described the four models.

Researcher *Which one do you like?*

Sylvia	*Well, I used to think that they clashed in the middle, but after you had explained it, I thought there was both the same electricity going in as there was coming out.*
Researcher	*Which was that one?*
Sylvia	*D.*
Researcher	*You think it's D?*
Sylvia	*Yes.*
Researcher	*How does it explain the battery going flat?*
Sylvia	*We played that game where one person was the light and each time they went past they took some cards to the battery.*

Interview extract two. The observer talked with Natasha in the one-month-after interviews. The part of this interview which is about Natasha's ideas on electric current is reproduced below.

Natasha	*I picked (model) B, because I thought that's the one. What does that one do?*
RJO	*Electric current comes out this way, and it also comes out this way, and it clashes in the bulb.*
Natasha	*Yes. Well, I didn't realise that the battery would go flat very soon.*
RJO	*Oh, the battery would go flat very soon?*
Natasha	*Yes. So I chose model C.*
RJO	*So you think C's the best? That the electric current goes out, and some of it goes back?*
Natasha	*Yes.*
RJO	*Then what's that model D there? Do you remember that one?*
Natasha	*Yes. That's when the same amount comes forward and the same amount goes back.*
RJO	*So you chose C?*
Natasha	*Yes.*
RJO	*What made you think model C?*
Natasha	*Well, quite a bit of the current comes into the bulb, and some of it is wasted up, and it can't take it all at once, so some of it goes back.*
RJO	*I see. Did you do some things with meters to check which is the right one?*
Natasha	*Yes. And we found out that D worked with the meter.*
RJO	*That D worked with the meter?*
Natasha	*Yes.*
RJO	*Uh-ha. But you prefer to think about it like C?*
Natasha	*Yes.*

RJO *What is it really like, do you think? If the meters say D, and you feel it's like C, and you used to think it was B, what do you think it's really like?*

Natasha *Well, if you had a meter you could do D. But I don't understand D.*

RJO *You don't understand D?*

Natasha *No. But I understand C, because if you (think it is D) you are not using up any power here. So how's it going on?*

RJO *I see - it doesn't make sense?*

Natasha *No. Is there power in a meter that it gives to the bulb?*

RJO *No. The meter just reads how much electric current there is.*

Natasha *Well, I don't understand D, and how that works, but I know it works, but I don't understand how it works.*

RJO *So, C makes sense to you?*

Natasha *Yes.*

After a further five months a similar interview was recorded, this time with the researcher as the interviewer.

Researcher *Can you remember what we did last year?*

Natasha *Mostly about electric current. We did kind of experiments with switches where current goes around, and the traffic lights, and doctors' call code, and things like that.*

(later)

Researcher *What do you remember about the meters?*

Natasha *Oh, yes. When they tested a different current. You put one on, and you say that the same amount was going back that was coming there.*

Researcher *Could you tell me that again?*

Natasha *Well, I think we joined a meter on to the wires, and we found out the same amount was going there as was going back.*

Researcher *That's how I saw it too.*

Natasha *Yes, because you had two meters on, and one was going forward, and the other was going back. They were both having the same amount of energy.*

Researcher *Here's how we write it down* (Researcher sketched the models A-D.)

Natasha *I like C.*

Researcher *Tell me about C.*

Natasha *Well it seems they take quite a bit out and you put it to the light and the part that they can't use they bring back. They've got so much in*

	there they bring it back and it gets put back in the battery, and it just keeps on flowing round so you've got an amount left in the battery.
Researcher	*That's a nice way of thinking about it.*

(later, in reply to a question about the teaching approach)

Natasha	*We discussed our opinions on the different matters like the batteries and things like that.*
Researcher	*Does it matter that people have different opinions?*
Natasha	*No. I think it is good to find out what other people think about it. And so you don't see it from your point of view.*
Researcher	*Do you know what Sylvia thinks about it?*
Natasha	*She thinks that D works.*
Researcher	*Does it matter that kids have different views?*
Natasha	*No, I don't think so. It's good seeing what they think of things.*
Researcher	*And what about the scientists? What do they think?*
Natasha	*I think that they think that D works...or C. But I don't think they think it's A or B.*

Comment. These learners knew what their prior ideas were, and why they had adopted them. They have adapted their ideas on electric current. Both had accommodated a new view; in Sylvia's case this was model D, whereas in Natasha's case it was model C. Earlier allegiances were retained. Analogies had been used to make links to new ideas.

Learners' Views on the Technological Problems

The learners referred to the problems, or puzzles, as being the most enjoyable part of this programme. This was noted by the researcher during the teaching, and some nine months later in individual interviews when learners responded to the question *What was the best thing you did that you can recall from the teaching?* Of the 15 in this sample, 12 learners replied with a description of one of the technological problems. Three mentioned the Christmas tree lights problem, four said that the traffic lights problem was their favorite (all females), two recalled the railway tunnel problem, and there were single mentions of the problem about the deaf person's door alarm and the doctor's call code.

Interview extract three. An example of the comments the learners offered in these interviews was:

Sylvia	*I think the best was when we started to make traffic lights. We were soldering some wires onto the little light bulbs, the different coloured light bulbs. And then we put them into tubes, and set them up so they'll work....*

In reply to a question about why that had been so interesting, Sylvia said

> *I think because after we had worked it out on paper we actually got to do it. If we had just worked it out on paper we would never have known if it had actually worked. There might have been something wrong with just the planning of it. It was nice to... it was quite a difficult problem but we managed to get it going to quite an advanced stage.*

The Stability of Learners' Views on the Electric Current Models

Information about each learner's model for electric current extracted from interviews and from a written survey given at different times is summarised in Table 5.3.

Leaving aside the data obtained two months after (because so many were absent), learners' views can be seen to have changed in the intended direction in seven cases. In the other cases, the view often reverted to the original, but not always. This process of change has been called regression (Cosgrove, Osborne and Carr, 1985a). While all teachers know about it ("They knew it on Friday but by Monday they had lost it!" is a familiar refrain) this research provided an opportunity to look further into this effect. Two studies were carried out. The first, a longitudinal study of six of these learners over three years is summarised next. The second, undertaken by Gauld (1986), to study the views of a sample of learners from a further trial, will be described briefly in chapter 6.

A Longitudinal Study of Learners' Views

A group of six learners (reduced to five when one left the district) was chosen to follow the stability of their views. Each of these learners supported model D in the surveys and interviews after the teaching. The data provided by surveys and interviews about their views of electric current are summarised in Table 5.4.

After nine months, four of these learners selected model D in responding to a survey. When they had completed the survey the researcher asked each to record his or her personal preference. This information is summarised in Table 5.5.

Table 5.3: Learners' models for electric current.

Learner		before challenge phase	just after challenge phase	two months after	nine months after
1	Mark We.	C	D	-	C
2	Mark Wr. ^	C	D	D	D
3	Adrian ^	C	D	D	D
4	Darren	C	D	-	C
5	Stephen ^	D*	D	D	D
6	Richard	C	D	-	D
7	Conway	D	D	-	B
8	Eldon	C	D	-	D
9	Craig	C	C	C	B
10	Inge ^	C	D	D	C
11	Sylvia ^	C	D	D	D
12	Karen I.	C	D	-	D
13	Karen B. ^	C	D	-	C
14	Natasha	B	C`	C	C
15	Rachel	C	D	-	C

^ indicates people who were part of an on-going study. Mark Wr. left this sample when he moved to another secondary school.
* identifies Stephen who stated that he thought that model D was a good way of explaining current, but which he could not support with any reason, whereas he could support model C even though he had some doubts about it.
\- indicates that these learners were not available on that day.

Table 5.4: Selection of electric current models by five learners.

sampling type >	[1]	[2]	[3]	[4]	[5]	[6]
<u>name</u>						
Adrian	C	D	D	D	D	D
Stephen	D*	D	D	D	D	D
Inge	C	D	D	C	C	D
Sylvia	C	D	D	D	D	D
Karen B	C	D	C	B,C	D	D

Key
[1] is the view held before the critical lesson.
[2] is the view held after the teaching.
[3] is the view held nine months later.
[4] is the view held 17 months later.
[5] is the view held prior to a second teaching episode, 36 months later.
[6] is the view held after a second teaching episode, at 38 months.
* indicated that Stephen selected the D view, but he could offer no supporting evidence, and he had some affiliation with model C.

Table 5.5: The group of five - their preferred models.

name	model from survey [3]	personal preference
Adrian	D	*D is sort of right*
Stephen	D	*I like C*
Inge B	D	*I like D*
Sylvia	D	*I like model B*
Karen	C	*I like model B*

That the prior and personal views of these learners existed alongside the new view for a considerable time is again demonstrated by these data in Table 5.5. One learner, Sylvia, remembered her affiliation to model B at 17 months, while also agreeing that model D had the better supporting evidence. At 36 months Sylvia did not refer to model B, nor did the interviewer (the researcher).

<u>A second electricity learning experience.</u> These learners took part in a second electricity unit in which their teacher (who knew about this research) blended the Osborne models with the traditional programme. This took place between 36 and 38 months after the teaching with the researcher. The teacher reported that these five learners were highly interested and attentive (as were some other learners), and their ideas were much clearer than those of most of the others. At the end of this teaching episode the teacher considered that most of her class had gained a scientific view of electric current, and she suggested that a successful learner, who was not a part of this sample, be interviewed. Using the standard interview protocol (*Can you make the bulb glow? Tell me what you think is happening there. What is happening in the wires?* and *Would the current be the same in both wires?*) the researcher noted that this learner, Rachel, made these statements:

> *The battery puts out power, the power is the electrons, the electrons are the physical thing and what they produce is power. The power travels in the wires The filament is like a spark, it glows; you get a spark when you touch positives and negatives.*

On viewing a diagram of the circuit used in the critical test Rachel said

> *It (the current) should be equal...no, it won't be. This one (on the left side) should have more power (than the other), because the electricity's going from the negative and when it comes back into the battery it is sort of dead, sort of used. So it is not as great as it was.*

This learner had not yet completely sorted out the idea that the current is not used up, although it is likely that her views had changed and were changing.

Commentary from the Observer

The observer (RJO) attended some of the class sessions towards the end of this teaching programme. He noted in written comments which accompanied a tape recording of interviews that, in his opinion

- the interest levels were high
- all learners kept to their tasks
- there was much learner experimentation
- he found it extremely difficult to determine who were the capable learners and who were the less able.

This observer interviewed the class teacher after this session, and some of the learners (after a period of four weeks). The observer noted that the class teacher used the opportunity of having another person teaching her class to be actively involved in the work of groups, and that the learners keenly told her what they had done. The regular teacher commented to the observer:

<u>On the class performance generally.</u>

That the class involvement was and had been high throughout the entire programme, and that the learners were happy and animated.

That the learners were not merely playing but were trying to work things out.

<u>On some of the more difficult class members.</u>

That there was an unexpected level of confidence amongst these learners.

That specific learners who she suspected of under-achieving in their ordinary lessons, had, on becoming involved, been able to verbalise better than usual.

That potentially disruptive learners had achieved feelings of success, they joined in with the more able learners and they offset the usual monopoly that the high achievers exerted in classroom discussions.

<u>On specific behaviours.</u>

That some learners were not resorting to trial and error approaches but were preferring to puzzle things out first.

That the learners were fluent in their use of technical terms, and that there was more language development in this approach than in typical school science lessons.

<u>On the researcher's teaching approach.</u>

That the researcher did not tell the learners any answers; rather they seemed to progress by reporting a series of discoveries which were then the basis for further finding-out, and this had an accumulative effect.

That the time allocated for each lesson (notionally 60 minutes) was greatly exceeded without any fall-off in interest or attention.

That while this approach was different from the normal approach to science teaching, she considered that she could teach like this now, provided there were highly structured resource packages available.

Commentary

The data presented in this study can be summarised under two main headings.

Learners' views. The learners brought to these lessons their own ideas on how to deal with their observations about electricity. These ideas might have been in the form of antecedents or schemata about events (for example, in which things are consumed), or they might have been already formulated as explanations (such as a model B view of current). These ideas and explanations were usually strongly held and few seemed uncertain about their use. It was difficult to change these explanations, and the changes that did occur were unpredictable. With care, and after a long time, change was effected in the direction of the scientific view after considerable instability and with some regression to prior views. The critical experiment was treated as another piece of information of no great weight, to be considered alongside their prior ideas. Some learners responded to an introduced analogy and used it as a way of coping with the experimental evidence.

Problem solving. These learners needed no instruction in how to solve the problems. All were able to penetrate some of the problems with varying degrees of success. Some supplied solutions which were both elegant and indicative of deep understandings. Learners were confident, their attitudes were positive, some previously identified as slow were not the only ones to experience frustration, and learners with behaviour problems accepted this programme. Some learners went further than the suggested tasks and developed their own problems. The researcher, observer and teacher all reported learners' satisfaction with these problems, particularly with those which were open-ended. During the lengthy period of problem solving, sophisticated analysis occurred. These problems were recalled with obvious satisfaction during later interviews.

General points. Some general points are noted here and will be returned to later.

1. Learners were confident that they could find out explanations.
2. These learners, who had had little experience of school science, did not expect to be told answers.
3. Five of the learners concluded that current is conserved, a different conclusion from a familiar error that electric current is constant (1).

The work opened up a curriculum design perspective in which a core concept was given central attention, with other related but less important notions being treated incidentally.

Modifications. It was decided to trial this package further to expand the roles of learners in the critical experiment, and to explore analogical reasoning.

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(1) The idea that current is constant is true for a particular circuit, but if the circuit is changed by the addition of a controller or resistor, the current will change.

Part 2: A Trial at a Secondary School

The Situation

Almost concurrently with the first reported trial a second trial was undertaken in a girls' college.

Entry. The teacher of a fourth form (ages 14 - 15 years) offered her class of 30 females for nine periods of one hour for three weeks.

Purposes of this trial. This trial investigated the impact of this teaching package on form 4 learners in the more highly-structured teaching conditions of a secondary school and examined the effects of learners conducting the critical lesson themselves.

The Teaching

The teaching proceeded with the researcher as teacher, and with the regular teacher (RB) and a researcher-colleague (CRT) as observers. The latter attended some of the classes in the familiarisation phase, and also the critical lesson in which learners' views were debated and tested. This observer interviewed two learners after the teaching had finished.

The familiarisation phase. This was taught in the same way as outlined in the previous trial, occupying five of the nine one-hour periods available. Much effort was put into encouraging learners to explore their own ideas, rather than being given the information to write down.

The challenge phase. In the one hour set aside for this phase, the learners were introduced to the models proposed by Osborne. Some proposed a fifth model. This model, called model E and regarded as a variant of model B, has two counter-circulating currents continuing completely around the circuit.

The critical experiment. These learners conducted the critical experiment themselves. They were supplied with ten pairs of ammeters (the type with three scales 0 - 5 A, 0 - 500 mA, and 0 - 50 mA, and with three combinations of terminals). The impact of this experiment on learners' views is summarised in Table 5.6 (column 2).

During the critical experiment to measure the currents in each arm of the circuit the learners showed that they were unskilled in attaching the ammeters in the circuits and in obtaining a reading of the current. These learners demonstrated that they were not used to doing their own measurements, nor were they able to make meaning from the numerical data of these current readings. While some of these learners had tried to obtain data and reach conclusions from it, most would have preferred to have been told what to record; they regarded the intervening activity as a game of little consequence to learning the facts.

The application phase. This was reduced to two hours as that was all the time that remained. Consequently very little was achieved in the way of concept stabilisation as the researcher-teacher was required to spend most of this time with learners who wanted to continue to explore the implications of the critical experiment.

Survey data. The responses to the electric current models made by the learners are recorded in Table 5.6, along with data recorded at various intervals afterwards.

Table 5.6: Learners' selections of models.

model chosen	before the critical experiment [1]	just after the critical experiment [2]	six weeks later [3]	thirty weeks later [4]
A	0	0	0	0
B	4	3	1	2
C	0	0	13	12
D	7	18	10	11
E	9	0	0	0
n=	20	21	24	25

Key [1],[2] - these data were obtained by a show of hands
[3] - obtained from survey 1 (appendix 5.2)
[4] - obtained from survey 2 (appendix 5.3)

The variation in the number of responses in each of the four surveys is due to two main effects: in order to gain the learners' confidence it was decided that it would not be compulsory to make a selection in any particular survey; also the learners were often absent from class for other learning purposes (e.g. instrumental music) and to assist in school administration.

Comment. This trial took place in a short space of time. The learners took some time to depart from their practice of recording notes as the principal activity in science. They lacked experience in articulating their ideas and appeared threatened by being asked to do so. This resulted in learners negotiating for anonymity at all stages, so that it was not possible to follow individual learner's views over the period of 30 weeks. The learners were not confident in the use of ammeters during the critical experiment and they were not convinced that the current readings so obtained were true. They wanted to know more about what ammeters did before accepting the information.

Summary of Interviews

Six weeks after the teaching had concluded and when the learners had returned from vacation, the observer (CRT) interviewed two of the learners. Their comments are summarised here.

Donna. This learner identified model B as best describing her understanding of electric current. She said that others thought that this was not right, but she could not deal with the idea of the battery expiring if she moved away from model B, and the information from the ammeters supported her view. Model C had some merit, except when the information from the meters was considered. She liked being able to experiment by herself, and the problems presented a challenge which she enjoyed. She noted that the researcher when teaching did not answer her questions directly, and while this was upsetting, she recognised the difference between the teaching approach and normal teaching; for she commented that

> *when people say you've got to do this, and you've got to do that, I tend to do it quickly and not think...but when you are just given it and he says, just suggests things to you then you've got room to do what you want...*

Justine. This learner accepted model D. Her reasoning was

> *Where else could it go except back? But then I still had the problem how did the battery go flat? And then I decided that it must be the chemicals being turned into electricity but not being able to turn back into chemicals again.*

Justine said that she had learned a lot, was able to use the electrical code to construct circuits, and proposed solutions to the problems. Having a chance to find out for herself was an important feature of these lessons which she appreciated, but she felt that she needed an answer at the end of it.

Commentary

On the survey data. The broad trend was that learners changed to model D and later changed again, back to an earlier model in some cases, or to another model. The learners in this class were most reluctant to declare their views and insistent on making anonymous replies. So there is no way of telling if the learners who selected the model D response in survey [3] were the same people who selected model D in survey [4]. It is clear that their ideas are unstable and that the survey [2] views cannot be taken as the long-term learning outcome.

On the critical lesson. The observer noted that the data provided by the ammeters caused much confusion in the group of six learners which he observed closely. He described how the learners had difficulty in understanding a circuit drawn in the electrician's code. He suggested that the diagram should be semi-translated into a sketch of the actual components first, so that the learners would be more likely to construct it accurately. The regular teacher agreed that unless the teacher intervened, there would have been little likelihood of these learners constructing a circuit needed to test their theories. The regular teacher was also concerned that the learners remain on task, rather than using the equipment to explore other effects and events which was seen by this teacher as deviancy, but interpreted by the researcher as exploration and play; these learners were indicating that they were not ready for the theoretical aspects of electric current until they were more comfortable with the associated ideas and equipment. The teacher was concerned about this deviation because in this trial there were effectively three teachers in the classroom, yet even with this higher ratio of teachers to learners the teacher claimed that there was much off-task activity. The teacher said that she considered the topic as presented in this format was too difficult for fourth form learners. The teacher also felt that the unit could not be accommodated in the usual school science programme if it required more than a three-week, nine-period block of time.

On the terminology. The observer noted that the idea of positive and negative readings on the ammeters caused this class some difficulty. Osborne (1984) considered that these terms should not be used in the initial stages and had suggested terms such as 'in' and 'out'. However 14- and 15-year-old learners do use the terms 'positive' and 'negative', and they need to be clarified and not simply replaced. While the main thrust of this project was to help learners' to clarify their ideas on current, it seemed that that notion had been enmeshed in a set of technical terms associated with electricity.

On the readiness of these learners. These learners took several periods in the familiarisation phase to adjust to the researcher's approach to teaching, but then they responded with a deluge of questions about electrical phenomena. Many of these learners came from farms, and they asked questions about electric fences and the responses of farm animals and birds to electricity (On reflection this is where the teaching of this class could have commenced).

While learners' initial reluctance to take part in this type of learning was overcome in the familiarisation phase, it returned when they were asked to make public their own selections of the models and their reasons. These learners considered that their part in learning was to record information.

The researcher concluded that a longer familiarisation programme was needed. This might need to be separate from any teaching of the electric current concept because learners were expected to deal with this package through an approach with which they were unfamiliar. In the challenge phase these learners were unable to use the ammeters expertly and there would be little point in going on until this had been achieved. The implication is that curriculums should be designed with extensive experiences before a critical experiment is planned.

The observer said that the topic could have been made more understandable if circuit diagrams were presented in an expanded form corresponding to the particular equipment being used. For the researcher the alternative which presented the greater likelihood of achieving competency was the provision of more experiences of making circuits from circuit diagrams, and making current measurements as part of these experiences.

Regression. The survey data showed that learners' views on electric current were unstable in the period after the critical lesson, and in a survey given some six months later less than half of the class identified model D as their view.

Constraints. A number of constraints were identified in this trial. The pressure imposed by a tight timetable and many interruptions prevented the desired thoughtful investigation by the learners. The comparative inexperience of the normal teacher may have been another factor which contributed to this outcome. The researcher's teaching approach differed from that teacher's, as noted in the long period needed to establish a working relationship, and in the learners' reluctance to expose their own ideas other than anonymously.

Gains. Some of the learners responded to the freedom provided to explore their own ideas and the few technological problems that were attempted were positively viewed.

It was not clear yet why this concept was so impenetrable to these learners. The researcher has had to consider, on the advice of many teachers, whether it was too abstract for 15 year-old learners. However, the 11 year-old learners had been at least as successful as the older learners, so an age-linked or stages notion was not indicated. It was possible that by 15 years it was too late to start the process of critically investigating electric current.

The clash between the expectations of learners and this teaching approach without sufficient time to become familiar with the approach led to a further trial being planned in more relaxed circumstances.

Part 3: Trial Three at a Girls' College

The Situation

Entry. A further trial in another girls high school was undertaken to address the research questions, and particularly the question of how this approach to teaching would fit in under normal conditions. The teacher was experienced, and less likely to be bound by perceived timetable constraints. She had written to express her interest in the aims of this research project, which she had heard about at a Science Teachers Meeting. In her view the school science curriculum did little for female learners. Students who had been successful in learning physics had told her that they studied physics only for entry to some professions. Also she was concerned that most young females do not have much idea of what, for example, an engineer does, nor about how one might become an engineer.

The class. The class of 29 females was an unstreamed fourth-form from a middle band (ages 14-15 years) considered by teachers to be a reasonably good class to teach (a top class of 30, and a bottom class of 30 had been streamed off).

The three phases. This teacher used a learners' workbook which had been developed for the topic. There were no modifications to the originally designed unit. More time was available in comparison with both of the earlier trials, and the challenge phase was expanded to allow more learner-controlled exploration and discussion.

The data. The complete class set of workbooks was returned to the researcher after the teaching. One of these is reproduced (Appendix 5.4).

Surveys. The learners' views on the Osborne models for electric current were surveyed during and after the teaching. The results are summarised in Table 5.7.

Table 5.7: Selection of the electric current models, trial three.

model	before the teaching [1]	after the teaching [2]	at end of the unit [3]	after three months [4]	after six months [5]
A	0	0	]	0	0
B	9	4	] 0	19	0
C	5	15	]	0	9
D	12	7	26	10	20
n=	26	26	26	29	29

Note 1: the sample size was 29; differences from this figure reflect learners' absence from class and not their un-willingness to participate in these surveys.

Note 2: the surveys used here were:
[1],[2] - data obtained from the learners' written views in their workbooks
[3] - using survey 3 (appendix 5.4)
[4] - using survey 4 (appendix 5.5)
[5] - using survey 4 again.

Comment. The learners completed all of the first and second sections of the workbook (corresponding to the focus and challenge phases of the teaching package).The learners' reports on each of these problems have been classified by the researcher as being satisfactory or partial. The classification as satisfactory was made if a conclusion had been reached, and partial if the problem had been explored without reaching a conclusion. Five of these problems had been attempted successfully. At the conclusion the learners were able to write their views on the unit.

Table 5.8: Trial three learners' reports on the technological problems.

Name of problem	Learners' reports on their solutions	
	Satisfactory	Partial
1. Christmas Tree	17	7
2. Railway Tunnel	25	2
3A. Traffic Lights,part 1	22	1
3B. " " 2	9	0
3C. " " 3	3	1
4. Call Code	18	0
5. Car heater switch	0	0
6. Mine lights	0	0
7. Car indicators	25	0
8A. Door bell	10	0
8B. Deaf person's "bell"	0	0
9A. Motor speed	13	10
9B. Motor direction	0	4

Teacher's Commentary

<u>On the teaching package.</u> This teacher wrote about her class' progression through the unit. The main points from her report were:

1. *The workbook impressed the learners and they enjoyed working through it. It was clearly printed and well set out. I have outlined what I think you could do to improve it.*
2. *Safety; this was a good lesson with active class participation. We enacted a scene (finding a body lying on a wire) and went through an isolation-rescue-breathing routine.*
3. *Making the bulb glow; I found this section interesting. In the past I had always given out the bulbs in bulb holders and wires with plugs on them and making the bulb glow has been straightforward. This time I decided to follow the suggestion in your manual and gave out just bulbs and covered wires. It was quite fascinating to watch students try to do this - very similar to the students on your videotape (some of whom were nonplussed by the covered wires).*
4. *Morse Code; well received. Students highly motivated. One student returned the next day to tell me that this code is the International Code, Morse is slightly different.*
5. *Describing the circuit; I am not sure that the time spent trying to emphasise the point, that writing a description is difficult and inaccurate, is worthwhile. I would probably leave it out in the future.*
6. *Extending the signalling equipment; unfortunately I was away ill when the class tackled this. They did not really do very much and the relieving teacher felt that a more structured lesson or worksheet would have been better.*
7. *The constructor's code; when I saw this I thought it was basically a load of rubbish but I would try it anyway. I was surprised at how quickly my students grasped the code and how easily they wired up these circuits. I felt however that the questions in the workbook could be worded to guide the students to a conclusion or to give them some ideas as to what to look for; e.g. compare bulb 1 with bulb 2 - which bulb is brighter? I found it impossible to get around ten groups all doing practical work and pose key questions at the appropriate times; also the mental gymnastics of coping with all these different problems - checking the wiring for different problems was too much to cope with without the students realising what to look for.*
8. *The electrician's code; many students were now reluctant to give away the constructor's code; they said that they knew they had the circuit "right" and if it didn't go it was probably loose wires and not something else. With the electrician's code they seemed to feel there was more likelihood of wiring things up back to front or wrong. I felt that drawing circuit diagrams was fairly important and I got them to draw all the circuits on the previous pages.*
9. *Summary of learners' knowledge; a good review lesson.*
10. *The critical lesson; as a lesson this went quite well although students mainly suggested (model) B and C without prompting. Many students commented that they did not really*

know what they were meant to write down in the boxes. They had formed an opinion about the model but found it difficult to explain why they thought one was right and the others wrong. I think many voted on "intuition" or on what they thought I knew.

Pairing up students with opposing views worked reasonably well with some "fierce" arguments developing but again I felt students had very little to argue with - just the fact that they "knew" one was the correct answer. Where I introduced ideas, e.g. batteries going flat, instantly half the students changed their minds to C. Again they didn't know what to write in the boxes. They did enjoy the voting, however they changed their minds frequently.

11. *The critical experiment; this was an exciting lesson which really built up to a climax - I thought the whole class was convinced at the end of the lesson.*

<u>The technological problems.</u> *I decided to try out as many of the problems as I could.*

12. *Christmas tree lights; are the terms series and parallel deliberately left out? Students were not sure what they should write down apart from the circuit diagrams.*
13. *The railway tunnel problem;...I felt that this was a good problem but rather too difficult at this stage. I would probably try it later or introduce it with a set of questions.*
14. *Traffic lights problems; these went well and were coped with adequately without much help. Students did not really know what they were meant to write in their books. They particularly enjoyed these.*
15. *Devising a binary code; a good thinking problem. I set this as a problem without using equipment, which was a welcome break.*
16. *Car indicator lights circuit; students enjoyed this problem and they were interested in the use of bimetallic strips. It would be interesting to look at these perhaps in an aquarium heater.*
17. *Electric motor problem; a popular exercise which went well; all enjoyed it and did it quite successfully.*
18. *Changing the speed of an electric motor; only two groups attempted this and were not able to find a solution on their own.*

<u>The outcomes.</u> *By the time we had finished the unit the students were reasonably competent at wiring up circuits, drawing circuit diagrams... but they became increasingly frustrated with loose wires, loose bulbs, wires falling off, i.e. minor problems which tended to slow them down.*

I was happy with the way the unit had gone and was reasonably confident that they had a fair sort of concept of the electric current. I set a unit test consisting of ten easy multichoice questions and some short answers comparing brightness of bulbs in different circuits. As a matter of interest I included a question asking students what they understood as an electric current. I have copied off their answers. At this point I became totally disillusioned. How some of them ended up thinking what they do is completely beyond me. Obviously the demonstration (i.e. walking around the circuit) has completely confused some students. At *the time I thought they really did understand what they were doing and what it was meant to show. However if I hadn't posed this question in the test I think I would have been reasonably happy with the unit, and would have felt that it was successful. It seems that these terms amps and volts have very little meaning to the students as yet. They use them frequently in their answers without understanding, interchanging them with each other. Perhaps it would be better to leave them out altogether and talk about energy and charges.*

A Learner's Comments

The workbook compiled by Michelle is reproduced in Appendix 5.6. Of particular interest are:

1. The full account of her reasons for preferring one model (D) (pages 16 and 17 of her workbook).
2. The solutions to eight of the practical problems.
3. Comments about her learning (reported on page 36).

This learner presented her own ideas about electricity. On page 8 she wrote:

> *When we had two cells and two bulbs the light wasn't as bright because more energy was needed for two bulbs.*

Later she recorded her reasons for preferring model D:

> *I think that it is an even flow all the time to make the bulb go.*

And confirmed this:

> *This is correct. It is a steady flow with wires being renewed with charges at the cell. I have come to the conclusion that the same amount of electricity flows all round the circuit.*

While she discarded the possibility of model C being a sound explanation because

> *you have to have a steady flow which is renewed with energy after each current has been round the circuit.*

And dealt with model B similarly

> *the electricity flows in one direction to be renewed at the cell after each round.*

This learner presented a two-component model for electric current which could have been developed in two ways. In the first, the system could be thought of as behaving as a carrier, with something (the energy in her terms) being carried from the battery to a bulb. In the second, her idea that the current is renewed with energy could have been explored to see if the notion of the battery acting as if it pushed the charges round the circuit could be developed. In a later trial (chapter 6) there were five instances of learners generating ideas which a teacher might recognise as being close to scientifically interesting ways of thinking about electric current.

For this learner and many of her peers the first goal of eliciting and elucidating her views on electric current had been achieved. The second goal, of developing a conservation-based view of electric current, had been partially achieved by allowing time and space to devise a sensible explanation for the identical readings presented on the ammeters. The third goal, of simulating circuits from her everyday world, resulted in eight sound solutions being presented.

Commentary

Regression. This effect was again demonstrated, and an unusual pattern emerged from the three-month and six-month data. In the three-month survey, 10 of 29 learners selected a model D response, while in the 6-month survey, the number was 20 out of 29. Learners' responses are typically most unstable immediately after the teaching. In this case two different surveys were used and it is possible that the question on the three-month survey was too different from the background examples. Further in-depth study of challenging circuits might help to stabilise the concept.

Problem solving. Learners and teachers reported that the problems were well received, and the researcher noted evidence of effective problem solving in the accounts recorded in the learners' workbooks.

Gender effects. The 30 females who took part in this trial did not reject this treatment of a physics topic.

A further trial was planned to examine this issue.

Part 4: A Trial in a Co-educational Secondary School

The Situation

The school. This trial enabled a gender issue to be explored with teenage learners. Three teachers at a co-educational secondary school taught the original package to four Form 4 classes as part of their normal science programme. These teachers were briefed by the researcher (a one-hour meeting) before the teaching commenced. Each was provided with the teacher's guide (Appendix 4.1), and a class set of workbooks. For three of the classes the researcher was asked to manage the critical lesson. The other teacher, a physics specialist, invited the researcher to observe his teaching of the critical lesson and all other parts of the teaching.

Observations during the teaching. Two teachers said that they would prefer not to teach the critical lesson because they were not confident that they would be able to cope with learners' questions about the ammeter readings being the same. The teachers expected the workbooks to do the teaching; there was little probing of learners' ideas with sustained questioning. As a consequence many high-ability learners approached the material in the workbook by racing to complete all of the required responses. These learners did not carry out the investigations; they worked out what the answers should have been and recorded their deduced answers.

Data. The responses of the learners to questions 6,7 and 9 (which probed views on the electric current models) were analysed for differences between responses of females and males; these are listed in Table 5.9.

Table 5.9: Females and males selecting model D responses

Class	Females number for model D		total number	Males number for Model D		total number
4A	15		21	6		9
4B	13		21	5		10
4J	5		14	1		14
4L	7		15	4		11
total	40	out of	61	16	out of	44
ratio for model D	56%			36%		

Using a χ^2 test with Yates correction, this result is significant ($p<0.005$).

Comment

This outcome contrasts with the research of Stead (1985) and Kelly (1981) which stated that females did not succeed to the same extent as males when studying physics topics in secondary school. A similar significant success for females has been reported in a related study where three co-educational Form 6 classes studied heat in the technological context of refrigeration. In this case 70% of the females achieved a satisfactory or better standard, compared to 33% of the males (Cosgrove, Newman and Forret, 1987; Newman, Cosgrove and Forret, 1988).

Part 5: Trial of a Modified Package at a Girls' School

The Situation

This trial was planned to study the effect of modifying the familiarisation phase of the teaching package. The change was to bring three of the nine technological problems, to which there had been favourable reactions in earlier trials, forward from the third phase. This, it was thought, would strengthen the technological emphasis for secondary schools.

Entry. A teacher at a girls' college asked if her fourth form class could try this package. The class had 24 members aged between 14 and 15 years. The teacher considered that this class was a superior one, capable of handling a strong technological emphasis from the start.
The modifications. The researcher outlined his plans for this trial both verbally in a meeting with the teacher, and in a letter to her. A set of modified workbooks, one per learner, had the three-phase layout of the earlier version. Here the first phase was a set of three technological problems. The work on safety, communication and codes, and the summary of "what we know" was omitted. The second phase dealt with the critical experiment, to be addressed when the teacher judged her learners to be ready (this was expected to have been after four or five sessions). The third phase was a continuation of the technological problems. A class set of equipment was supplied by the researcher, except for ammeters, as it was thought that learners would be more comfortable using those that they were used to.
The observer. The observer of this trial, an internationally-known science education evaluator, attended ten of the classes and reported his observations and comments (Welch,1985).

The Teaching

The teacher changed the order of treatment from the start. The first activity was a discussion of the learners' responses to the four models of electric current. Learners were surveyed before and after this discussion, the data obtained are summarised in Table 5.10.
At the commencement of the second day, the teacher demonstrated the current in a circuit with ammeters placed before and after the bulb. She pointed out to them that the current readings were the same in both, without explaining what the meters were.

Table 5.10: Before and after selections, trial five.

Model	Before	After
A	1	1
B	20	13
C	4	15
D	3	0

To one learner who asked

If D is correct, why does the battery go flat?

the teacher responded

We would learn about that later.

The observer noted that the topic never came up again. This was the last class discussion during the unit.

The observer recorded that he was puzzled why the teacher started with page 12 of the workbook and then presented the crucial demonstration on the second day. However he did not ask her about this because that might imply criticism of her decision.

The problems. The observer noted that these learners experienced considerable difficulty in trying to solve these problems. In his opinion their lack of background knowledge and problems with the equipment made success a rare event.

The Observer's Comments

On the concept of electric current. The observer considered:

> *It was quite clear that the idea of a circuit was not understood by this group of students. Their attempts to connect the wires to get the bulbs to light or the motor to run were largely hit and miss. They never really understood the idea that a path was needed from the battery to the resistance (whatever it might be) and back to the battery.*
>
> *As I think about it now, I believe that an introductory unit on this topic must emphasise the circuit idea. Emphasising the equal current concept, i.e Model D, without any understanding of circuit is doomed to failure. It may be that the project has become so accustomed to the notion that the four models characterise the full range of alternative frameworks that some other misconceptions (and I use the term advisedly) exist which are creating other problems. The failure to perceive a circuit as a path for electrons may be one of these problem areas.*

This modified unit was not intended to be used as an introduction. That it was, was borne out in these observations

> *Several of the girls learned their initial fear of getting shocks was unfounded... There was considerable activity during the class sessions but much of it seemed to be quite unproductive. Without direction it was more like playing with the equipment rather than trying to learn something...I think the lesson for us all as educators is that equipment or tools in and of themselves do not ensure learning.*

On teacher preparation. The observer commented

> *Although it was stated in the written materials, it is clear that teachers need to be given more direction for their responsibilities in teaching a problem-oriented unit such as this one. One approach may be to concentrate upon teachers' questions and the alternative frameworks they hold regarding teaching. Greater understanding of the ideas teachers bring to teaching may suggest ways to ensure the unit is presented in the intended manner.*

Commentary

The outcomes of this trial point out a problem when a teacher wants to use an innovative approach without fully understanding the ideas on which the approach is based. It has become clear that the implementation of packages based upon different learning theories cannot be realised by preparing a package and passing it over to teachers. The teacher may have expected the materials to do the teaching (an effect often commented upon in science curriculum projects where extensive written materials are provided for learners).

The Research Questions

The principal thesis, that science can be learned in a technological context, and the sub-thesis, that different views of learning are needed for this, have been addressed through 12 research questions. Analysis of the five cases presented in this chapter has provided insights into several of these questions. (Other questions will be answered after chapter 6, or in chapter 7).

Questions About Technology

Two questions about technology can be answered. These will be treated individually.
Question 1: What is a suitable technological context for learning about electric current? This teaching package used the technologically significant notions of

survival	through electrical safety in domestic situations and how to treat a person with electric shock
communication	through Morse Code and several codes for describing circuits
control	by seeking solutions to problems initially based on domestic circuits, and then extending to industrial circuits.

Observers and researchers noted that learners became engrossed in the activities centred on these technological systems, that the sophistication in many of the learners' answers was high, and that some learners devised their own problems to investigate.

Question 2: What criteria can help in establishing technological contexts? The over-arching consideration used in selecting a context is that it be good for learning. This aim can be met through a set of criteria, the principal one being, particularly in the case of the problems, the relevance of the context to learners' lives. This criterion is linked to the purpose of science education underpinning this study; that it help learners to make better sense of their worlds.
A second important criterion is that the contexts be open-ended, so that learners can develop them further. For example, in the case of the Morse code, learners were able to explore ideas about the 'global city' and the impact of technological communication; or they may have wished to become proficient in sending and receiving Morse signals. Open-endedness can apply to the context being followed up later in the science programme, in other sections of

the curriculum and out of school. Each of the problems had this open-ended opportunity as well, and examples of learners' responses to them have been presented. Another facet to open-endedness is the capacity of problems to produce more than a single solution, and to produce solutions which can be further improved and refined. In addition, decisions which can help in establishing criteria are based on technological contexts being:

Engaging and **attention-gaining** in the sense that Papert (1980) and Osborne and Wittrock (1985) use these notions.

Accessible; can young learners understand the system or grasp the problem?

Realistic, and not contrived.

Of **social** or **economic significance**, and seen by learners to be so.

Illustrative of **modern technological principles**. There were indications that learners intuitively used proceedures such as optimisation,feedback and modelling as they elaborated and refined their solutions to problems.

Fruitful sources for the development of **scientifically-important concepts**, and providing scope for **scientific practices and habits.**

Balanced in the educational sense, so that they avoid gender bias, and sensitive to differences among learners, particularly those derived from racial and cultural pluralism.

A way of confronting the **social, moral, economic and political issues** embedded in the use of that technology.

As well, the criteria would need to avoid the tendency to promote technology as "physics with engineering" alone by bringing learners into contact with biological, geological and chemical contexts.

Question About Learning and Teaching Science

The question Can the learning needs of females (believed to have been disadvantaged in learning physics) be met? has been investigated in a general way in four, and in a specific way in one of the five cases reported in this chapter. The 11-year-old learners in the first study showed that they had few if any distinctions between the capacity of boys and girls to deal with this topic in this way, but the 15-year-old females in the second study did not cope well with this approach initially, and thus may be considered to have been disadvantaged by it. Some of these learners became more comfortable as it went on, but others remained perplexed by the requirement to expose their own views. The learners in the fourth study responded similarly, but the learners in the third study did not respond in this way at all. These different effects in three classes of 15-year-old females suggest that the effect is not general, and that it may be socially contrived by teachers or the schools they attend. In the fourth study, the physics learning of boys and girls was contrasted, and the female learners were significantly better. This may have been because of the context (females, it is claimed, are likely to be more successful where the physics is based on societally important events), or because of the teaching model (which encouraged discussion and debate).

Chapter 6

EXAMINING LEARNING IN THE CHALLENGE PHASE

The process of science is that of building a rational consensus.

John Ziman

Introduction

The Situation

The classroom episodes reported in parts 2,3 and 4 of Chapter 5 took place more or less simultaneously, because those secondary schools scheduled the teaching of electricity for the same month in the Form 4 year. There was therefore little time to reflect on the information provided or to modify the teaching approach. Subsequent analysis suggested that the challenge phase needed to be expanded and to be less teacher driven. This Chapter reports on an investigation with the following modifications:

1. The familiarisation phase began with the teaching of the constructor's code.
2. The first three problems from the application phase became the main part of the familiarisation phase (as had been intended in trial 5).
3. Ammeters were available in this modified familiarisation phase to allow learners to check their ideas about, for example, the brightness of lights and to become proficient in their use.
4. Explanations for circuit phenomena based on learner-generated analogies were sought.

The class. A fourth form from a boys' school was the third stream from the three-class top band, there being ten classes in this form, partitioned into three broad bands. The class was taught by its regular teacher, a physics graduate, in his third year of teaching. The observer considered that the teacher was clear about the research purposes. Provision of ample time for learners to explore analogies was provided. The result was a slower programme compared with the earlier trials.

Observations. The researcher observed all five lessons of an expanded challenge phase. The observer compiled notes, obtained information from two tape recorders used in each of the five reported lessons, collected examples of the learners' written work, and interviewed the teacher immediately after each lesson. The transcriptions were reviewed by the teacher and by colleagues of the researcher. Further information was gathered by administering a survey (Appendix 4.2) immediately after the teaching, and again after ten weeks. Later another researcher interviewed 15 learners from this class to describe the changes that could be detected after 12 weeks (Gauld, 1986).

Familiarisation phase. The teacher reported that this phase began with instruction on the use of the constructor's and electrician's codes for recording circuits, then the learners worked on the first three of the technological problems. The teacher decided not to use workbooks;

each problem was introduced on a hand-out sheet. The class spent four one-hour periods on this modified familiarisation stage.

The Observation Period

Day One

Learners' views. The ideas learners held about electric circuits at the commencement of the challenge phase were summarised by the teacher from a homework review. The points elicited were that two wires are needed, the wires must be conductors, a power supply was necessary, there had to be something to take the power (e.g. a bulb), the circuit must be closed, circuits can be drawn in different ways yet mean the same thing. The four Osborne models for electric current were then introduced and learners indicated their choices by a show of hands. A majority chose model B. This survey is summarised in Table 6.1.

Table 6.1: Numbers selecting each current model.

model selected	number of learners
A	0
B	16
C	7
D	5

The learners discussed their ideas as indicated in this selection of tape- recorded comments.

Learners opposing Model A.

There are two things, positive and negative, so two wires are needed.

There is no way a second bulb will go.

Learners supporting Model B.

The positive and negative come out of the battery, then clash.

With your tongue on one terminal there's no tingle; you need to touch both terminals.

Learners opposing Model B.

The wires would have to be the same length.

There's a circuit inside the bulb allowing the current to flow round.

Learners supporting Model C.

How else will the battery go flat?

If there's two bulbs in a circuit (in series) the positive and negative won't meet.

Learners opposing Model D.

The battery goes flat.

Learner supporting Model D.

The electrons are carriers, they drop stuff off at the bulb.

Comment. There was no support for model A. There was no opposition to model C, which was surprising considering that 21 learners did not support it. One learner who selected model D offered a two-component model of electric current in favour of model D, while the other learners who selected model D did not re-butt the point about the battery not going flat; one said that he was unable to explain it, but that he still considered D to be the correct one. Another learner said that models A, C and D were more or less the same thing, with so little difference that it was unimportant.

The critical experiment. The teacher prepared for the critical experiment with a painstaking explanation that there would be two distinct pieces of information from the meters; these ammeters would indicate both the size of the current and the direction of the current. Then the learners were asked to make predictions of the current (on the basis of their choices from the four models) for the reading on a second ammeter placed in the circuit when the current indicated by the first ammeter was 2 (*10E-1 ampere). The researcher obtained the predictions from 18 learners by note or by tape-recording (without interrupting the lesson), and this information, along with each learner's choice of a model, is contained in Table 6.2.

Table 6.2: Learners' decisions on the second meter readings for the critical test, and their selection of a model for electric current.

Name	Selected Model	Predicted meter readings for each model			
		model A	model B	model C	model D
Ross W.	D	0	2	1	2
Ross C.	B	0	-2	1	2
Darrin W.	B	2	-2	-2	-2
Matthew W.	B	0	2	1	2
Richard C.	C	0	-2	1	2
Aaron S.	D	0	-2	1	2
Brian K.	B	0	2	-2	-2
Grant R.	C	0	2	1	2
Ashley D.	B	0	2	1	2
David B.	B	0	-2	1	2
Aaron B.	B	0	-2	1	2
Ian J.	C	0	2	1	2
Jason B.	B	0	2	1	2
Simon O.	B	0	2	0	0
Paul S.	D	0	-2	1	2
Antony S.	B	0	2	2	2
Richard D.	B	0	-2	1	2
Benjamin B.	B	0	-2	1	2

Note: In several cases the learners responded for model C with an answer which indicated that the current would be less than 2 (*10E-1 ampere). This has been recorded as "1" in the model C column.

Here, 17 correctly predicted that if model A was right there would be no current indicated by the second meter. For model B all 18 predicted that the current would have the same numerical value, but nine did not attribute a negative value to indicate the reverse direction.

For model C 14 made sensible predictions, while for model D 16 predicted that the current would be the same in size and direction.

The use of positive and negative numbers caused much difficulty despite the teacher's awareness and careful preparation. This difficulty was expected (this much was known from the earlier studies, particularly trial two). The use of ammeters before the critical lesson was planned to offset this difficulty by attempting to provide some familiarity with the notion of directional information before it had to be used in making decisions in the critical lesson.

Day Two

The critical experiment repeated. When the class re-convened, the researcher joined a group of six learners which contained the one learner who had advocated model D and could justify his decision (noted above as a two-component explanation). The teacher repeated the critical experiment, this time with different apparatus on an overhead projector. A portion of the recorded discussion from this group was:

Teacher	*What do you think, Simon? Do you think that D is wrong?*
Simon	*No, I think it's all right now.*
Richard	*It must be right..but I don't see how the battery goes flat though.*
Benjamin	*It's strange, but it's true.*
Simon	*Theoretically we agree... but it can't be right, because why does the battery go flat?*
Ross	*Electrons are carrying energy, and they keep on carrying it in and taking it out, then they come back and get some more, allright? And then, slowly the battery gets less and less energy.*
Others	*No, no, no.*
Simon	*Get somebody who knows what he's talking about.* (To the researcher) *Could you explain it, 'cos it needs to be explained?*
Ross	*I asked an electrician. Its like a train carrying coal. It drops it off, then goes back to get some more coal.*
Learner	*Talk about light bulbs, not trucks!*

Ross then sketched his model on the chalkboard at the teacher's request. Ross explained that the only problem he could see with his idea occurred when two bulbs in series had to be explained. For him the problem was to understand how the first bulb knew that there would be another further down the line. He told the teacher later that he had not asked an electrician, but that he had said that he had in order to deflect the criticism of his ideas. Ross pointed out that his idea was useful in the case of parallel arrangements of light bulbs. For the circuit in Figure 6.1, Ross predicted that the current reading on ammeter A1 would be double that indicated by ammeter A2.

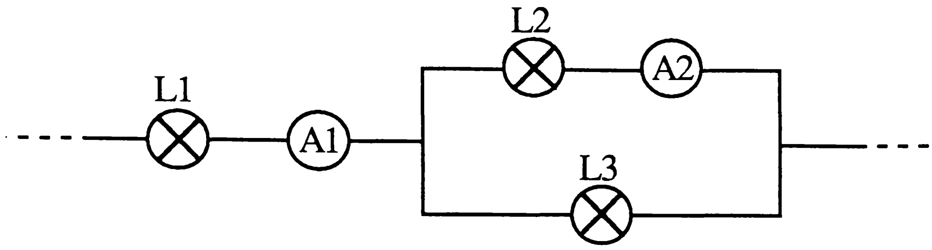

Figure 6.1: A circuit-segment with which Ross explained his theory.

Nearby, a group of six learners looked closely at the ammeters. They concluded that the meters did not indicate the same current at all; one showed a slightly smaller reading (which the researcher observed to be about a 1% difference). This was promoted as evidence for model C, and against model D by this group. At the conclusion of the second day, the class voted on each of the models again (by a show of hands). All but four out of 29 voted for model D. This vote is shown in Table 6.3.

Table 6.3: Class response to the models after the second day.

model selected	number of learners
A	0
B	4
C	0
D	25

<u>Comment.</u> This result would normally be accepted by a teacher as an indication of successful teaching and learning. The teacher would have felt justified in moving on to the next topic (as the teacher of trial three in chapter 5 noted). Gilbert (1984), commenting on the transcript of this trial, considered that models D and B might have been distinguished, but he was not sure that model C may not have been removed as an alternative. The researcher considered that the voting indicated which model each learner liked the best, but it did not allow for second and third preferences.

After two periods in the challenge phase, the teacher commented that:

1. He was aware there was much disturbance of learners' views, with a high degree of conflict.
2. Most of the learners wanted to resolve the disturbance by asking the teacher to supply the correct answer.
3. He had, on several occasions, found that he was about to tell a learner with whom he had held discussions the answer (to the learner's question) rather than to continue questioning if the learner was close to finding out for himself.
4. The peer pressure was acute.

5. He had tried to develop a strategy of reflection by asking learners to consider how fruitful an idea was.
6. Learners seemed to adopt one of two modes of action; the majority vigorously debated the issue, while a small group of three or four people appeared to be interested in the debates without taking active parts.
7. He did not trust the responses in Table 6.3. He was not clear about the reasons the learners had given for changing their views, and he considered there was an ambivalent air to their voting; it was as if the learners knew that Model D had to be the answer but they did not understand why. Because of this he decided to keep the topic open, rather than moving on to the application phase. He discussed with the researcher how this might be done, and he decided to introduce two circuits which the researcher had used elsewhere and which had been shown to be particularly thought-provoking and challenging. These circuits are represented in Figures 6.2 and 6.3 below.

Day Three

Challenging circuit one. In lesson three, five days later, the teacher began by explaining to the learners that he intended to concentrate upon developing their electric current ideas. This would be attempted through consideration of two circuits.

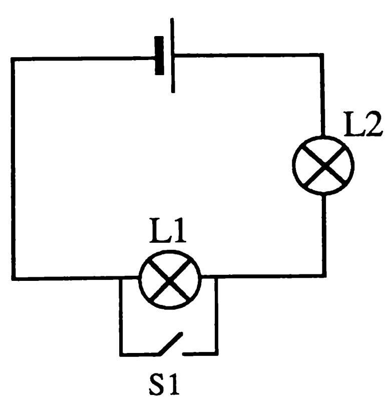

Figure 6.2: First challenging circuit (circuit A).

In circuit A, L1 and L2 represented light bulbs of the same power rating, S1 was a switch. The teacher asked *When the switch, S1, is open what would you expect to see? Think about this in terms of your ideas on what happens in a circuit.* The learners copied this circuit and recorded their predictions. The observer noted that most wrote that bulbs L1 and L2 would be equally bright when the switch was open. Two learners who did not make this prediction wrote that bulb L1 would be brighter than bulb L2.

Some learners used Ross's analogy of a train conveying coal to question how the current would have been able to decide to drop off half (of whatever it was that caused the bulbs to glow) at the first bulb. Another learner raised the question of how there could be an instantaneous response in which both bulbs emitted light at the same time, for (again using

Ross's analogy) this learner said that one bulb should have glowed first by itself, to be followed by the second a short time later. From the discussion the point emerged that some learners had interpreted Ross' analogy as a single truck circulating. Ross indicated that he considered that his analogy needed many trucks, perhaps a convoy, circulating.

Next the teacher asked the learners to predict what would happen in terms of any analogy when the switch was closed. His specific questions were

1. *Who thinks that there will be no change?*
2. *If you think there will be a change, what will it be? and*
3. *Are there any other ways?*

The predictions were

15 for no change

15 for L1 being dimmer than L2 (L1 < L2)

1 for both L1 and L2 being brighter.

A fourth idea, that L1 would be off and L2 would be on was put forward as a possibility, not as a prediction, by one learner who had made a different prediction. As a result of this last possibility, a discussion developed and two learners changed their minds. They reasoned that the current would split so that some current would go through the switch, thus L1 would be dull, and L2 would be brighter.

A new set of responses was recorded:

13 for no change (L1 = L2 and dull)

17 for L1 being dimmer than L2 (L1 < L2)

1 for both brighter.

When the learners tested their predictions, they noticed that both bulbs glowed equally brightly; then on closing the switch S1, the bulb L1 went out and the bulb L2 was brighter than before. No one had predicted this. Some learners asserted that there was an error somewhere. The following discussion was recorded.

Ian	*I want to ask a question; why don't they take the shorter journey and go through bulb 1?*
Teacher	*That's what I'm asking you to find out.*
Scott	*It's easier to go through switch 1 than bulb 1, because bulb 1 is wound up, its a resistance to the trucks.*
Teacher	*What do you mean by resistance?*
Scott	*There's a very thin wire, making it harder for the trucks to pass through.*
Benjamin	*Is Scott saying that the trucks take the easiest way they can go?*
Scott	*Yes.*

These learners brought in a new idea to deal with this unexpected event.

Challenging circuit B. A second circuit, as in Figure 6.3, was displayed as a drawing.

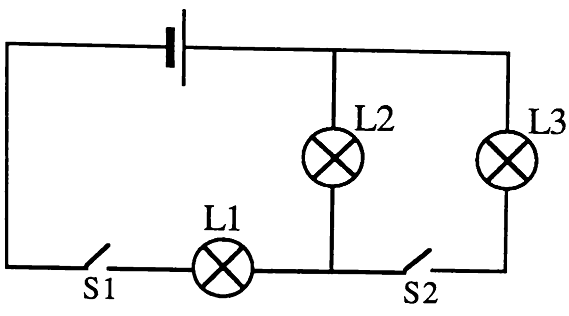

Figure 6.3: A second challenging circuit (circuit B).

The teacher described this circuit in four separate arrangements and sought the learners' reactions to each:

1. With both switches open.
   It was generally agreed that no bulbs would glow, as there was no circuit.
2. With switch 1 open and switch 2 closed.
   Again the predominant view was that no bulbs would glow.
3. With switch S1 closed and switch S2 open.
   The teacher asked if all three bulbs would glow. Many said that bulbs L1 and L2 would glow equally brightly, while one learner said that he thought that they would not be at the same brightness.
4. With switches 1 and 2 closed.
   Most agreed that all the bulbs would glow. They were not asked to compare brightness levels at this stage in the lesson.

Comment. This teaching strategy used by the teacher to talk through the details of the circuit showed his sensitivity to the difficulty which he expected the learners would have to circumvent in order to understand what the circuit means. He also recognised that learners have difficulty in interpreting the layout of circuit diagrams, as noted also by Joshua and Dupin (1985).

Next the teacher asked the learners to predict the comparative brightness of the bulbs in this circuit with both switches closed (arrangement 4 above). He elicited the possibilities, listed these, then asked the learners to select the one each preferred. Most said that they thought that bulbs L1 and L2 would be equally bright, and that bulb L3 would be dimmer. These predictions are summarised in Table 6.4.

Nicholas, the learner who had made the prediction that L1 > L2 = L3 (which was later shown to be the successful prediction) said that he would investigate this circuit with ammeters at specific locations when the class next returned to the laboratory.

Among the suggestions noted by the researcher were ideas like this:

Perhaps the electricity is scared of getting red hot, so it'll be cooler if it divides and goes half to L1 and half to L2.

Table 6.4: Predictions about the brightness of bulbs L1, L2 and L3 when both switches in circuit B (Figure 6.4) were closed.

Brightness prediction	Number of learners
L1 = L2 = L3	3
L1 = L2 > L3	18
L1 = L3 > L2	1
L1 > L2 = L3	1
no prediction	6

The teacher recalled this in discussion with the researcher later for his interest in the implication that a notion of resistance might be underpinning it. This point was not taken up by others (nor was Scott's comment about a thin wire being resistant to current). There were many such proposals throughout this teaching sequence.

A problem about the facts. At this stage a small group of learners expressed their concern to the teacher about the lack of facts, that all other teachers "tell us the answers", and that they had no "real proof" that would settle their questions about electric current. The teacher explained that he thought that they would soon be able to sort it out for themselves as they were very close, and they were appeased by this and returned to the questions.

Day Four

This lesson started with the teacher referring to the learner-expressed concern about where the teaching was aimed. The teacher re-assured the class that they would resolve their problems by themselves very soon.

There were three main parts to this lesson.

Part 1: Following up a prediction. The teacher asked Nicholas about his prediction (that L1 > L2 = L3) made in the previous lesson. Before that prediction could be explored, Nicholas put forward another idea.

Nicholas — *I've changed my mind. L3 will be brighter, and L1 and L2 will be the same but dim.*

Teacher — *Why have you changed your mind?*

Nicholas — *We've done the two-bulb circuit and we know that those two bulbs are the same brightness. In circuit two, with both switches closed, L1 would be the same as L2, and L3 would not be the same.*

Teacher — *The other idea you had was that L1 > L2, and L2 = L3.*

The teacher did not press for an explanation at this stage, preferring to give equal weight to each prediction. The learners tested the four predictions by making the circuit. While this was going on, there was a discussion amongst Nicholas, Neville and Andrew about whether switches were actually needed. Two of the group thought that a closed switch was the same as a piece of wire, but the other did not. His partners explained their view to him; however he was not convinced.

The teacher recommended that this circuit be made with three cells in series to produce 4.5 V instead of one cell (otherwise the filament temperatures would have been too low to emit any light). The learners accepted this recommendation without seeking an explanation, and the researcher concluded that they had not lost sight of the task in hand, which was to discriminate amongst four options. They observed that bulb L1 was brighter, and the bulbs L2 and L3 were equal and very dull.

Teacher — *So, it's bright-dull-dull* (*$L1 > L2 = L3$*)*. Who had that theory?*

Group — *Nobody.*

Nicholas — *I had that yesterday, but I changed it.*

Part 2: A discussion about model A. Stephen H. had asked his teacher (before the lesson commenced) why model A had been incorporated in the discussions, as there had been no interest in it except for a brief comment by the teacher. The teacher referred this point to the class, and Matthew thought that it might have some merit, for he proposed that

> *The energy travels around, the trucks are carrying it. It dumps it all off at the light bulb, and comes back empty to the battery.*

Ian added to this, saying that he thought that the return wire in model A had empty trucks in it. Nearby, a group of learners agreed that model A made sense for the 'energy' while model D made sense for the current. The matter was left at this point. This was the third recorded occasion in which an idea which meshed closely with other concepts or analogies had emerged spontaneously. There was no paucity of ideas like this, and the teacher did not deal with as it was his intention to bring the thinking about circuits A and B into focus.

Part 3: Explaining the two perplexing circuits. In the main part of the fourth lesson the teacher told his class that they had shown much persistence in trying to unravel the strange behaviour of electric current in circuits, and that he thought that many were now very close to a break-through in their understanding. The discussion then returned to the two circuits. A conversation on these predictions was started by one learner (name not recorded) who analysed the circuits in a novel way:

Learner 1 — *In circuit A Scott reckoned it was easier for the trucks to go through a switch than a light (bulb). And we proved that by doing it. And it went through the switch and it didn't go through lamp L1. So I think in circuit two* (Fig. 6.3), *the current of trucks will go through* *switch 1, then there's a switch there... it'll miss out L2 and go straight to switch 2.*

There was a retort:

learner 2 — *But then there's a light there as well (L3). It has to go through a light.*

Learner 1 — *It was the same over here* (in circuit 1).

Learner 2 — *When the switch* (is closed) *it's just like there being no switch at all; its just like a straight wire, isn't it?*

Learner 1 — *I suppose you're right, but that's my theory.*

Learner 2 — *It's wrong. It'll go through both.*

This discussion continued for several minutes more, but the language used was based upon much pointing to the diagram of the circuit without identifying the parts, so its transcription is of little value in understanding the logic of the discussion. The teacher noted that there was a sustained and intense discussion.

The teacher then continued his careful path through this stage by sketching circuit B (Figure 6.3) in a different way, as shown in Figure 6.4.

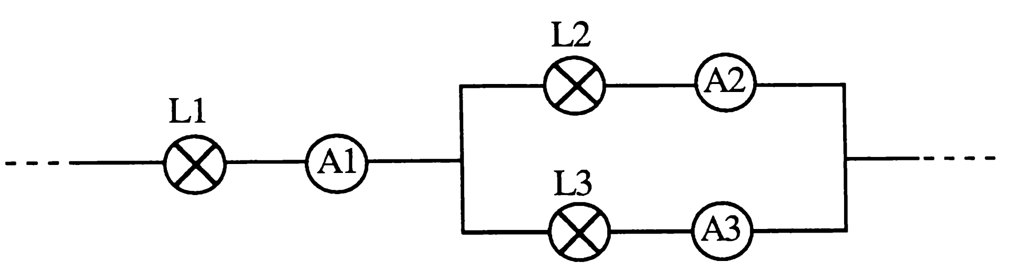

Figure 6.4: An alternative presentation of a part of circuit B.

Five learners thought that the circuit in Figure 6.4 was different from the circuit in Figure 6.3. The teacher made a careful explanation, including a demonstration of this conformational problem.

In a group, six learners continued the debate on their two predictions about the relative brightness of the three bulbs in the circuit shown as Figure 6.3. The teacher noted that Ian had predicted that the order of brightness would be L1 = L2 = L3, while Matthew proposed that L1 > L2 = L3; he probed their explanations.

Teacher — *What was your theory, again?*

Matthew — *Light 1 would go, and the other two would go, but not as brightly.*

Teacher — *But why?*

Ian — *Go and get three meters.*

These learners knew that they were expected to sort out such matters for themselves. This group placed three ammeters to measure the current as in Figure 6.5 (on the next page).

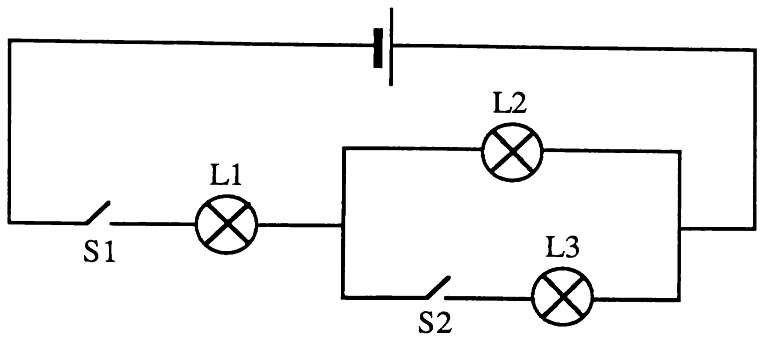

Figure 6.5: Circuit used to test a group's brightness predictions.

This group recorded these ammeter readings

<u>ammeter</u>	<u>current</u>
A1	300mA
A2	150mA
A3	150mA.

This group expressed its satisfaction that Ian's prediction had been established as the answer to their problems with charge flow. But they could not suggest why it should have been so. The teacher used the opportunity provided by Ian's and Matthew's experiment on circuit B (Figure 6.4) to ask the whole class to think about the possibility of the meters A2 and A3 having different readings.

Teacher — *Do you think that there is a way that they might split 100mA/200mA rather than 150mA/150mA? Do you think that is possible?*

From this a discussion followed:

Scott — *There could be different resistances in the bulbs.*

Another — *If they're looking for the quickest way, if they just had a little wire and a great big long wire.*

Grant — *When one bulb is bigger than the other and it needs more energy to get it going to a certain brightness.*

Teacher — *What difference does that make?*

Grant — *If L2 was a bigger bulb and it needed more to get it going, 200 could go to L2 and 100 to L3, which doesn't need so much.*

Teacher — *Are you saying that one route is easier than the other, or are you saying that one (bulb) requires more energy than the other?*

Grant — *One requires more energy than the other.*

Teacher — *Are they likely to go to the one that requires more energy?*

Philip — *If one has a small wire and (the other) a large wire they probably would go more to the larger wire.*

Teacher — *What does the larger wire offer, compared to the small wire?*

Antony *The bigger the wire the more lanes of a road for the trucks the less traffic will block up.*

Teacher *If we think of these as trucks, if we offer them a six-lane highway, or if you like a big thick wire, what you are saying is 'obviously they can flow down that a lot easier than if you offer them a narrow country road' isn't it?*

Antony *Exactly.*

Teacher *We will come back to this on Thursday* (two days later).

The notion of resistance in an electric circuit emerged again in a natural way from learners' thinking and through the development of their ideas, supported on analogical verification. This was a further instance of incidental development of a crucial idea from learners' notions. Here the notion of a resistor as consumer was proposed by Grant, while the teacher tried to challenge that idea.

Elsewhere a notion of resistor-as-regulator (implicit in the class's analysis of circuit A, Figure 6.2) had emerged in the analogical reasoning used by some learners. There were discussions about "finding the easiest way," with the filament described as if it was a hill, and a closed switch as a tunnel through that hill. While learners could recognise the route which the charges would take, they were not able to "decide how the charges knew to do this."

Day Five

The final lesson of the challenge phase. This lesson started as the others had with a learner's statement or question receiving first consideration. This time there was another example of analogy-based reasoning when one learner, Stephen H., proposed an explanation for the charge flow in circuit A. Stephen had written in his homework book:

> *When the switch, S1, is closed, L1 will be out, L2 doubly brighter than before. This is because the current finds it easier to go through the switch than through the light, because the current is held up in the filament.*

Stephen was invited to expand this explanation. He drew a diagram on the chalkboard which the observer copied (Figure 6.6).

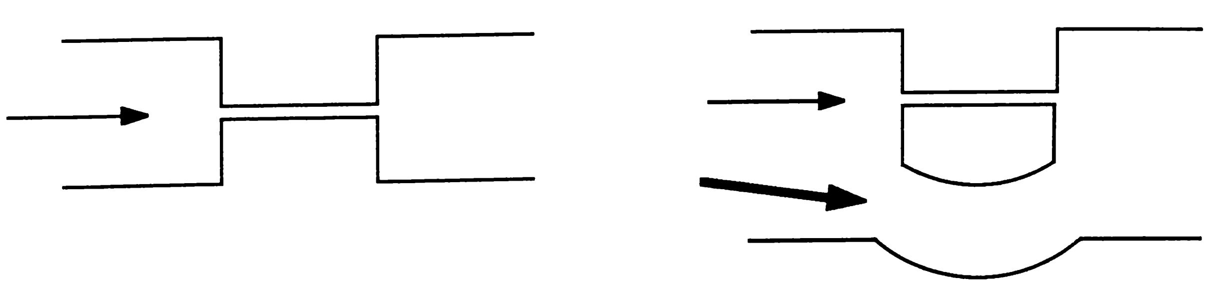

Figure 6.6: Stephen's drawing to explain circuit A using a flowing water analogy

The teacher tried to find out if Stephen had been told about a flowing water analogy (as this is a common explanation given for electric current), or if he had thought of it by himself. On the evidence available, it seemed that Stephen had generated the idea himself, for he had written:

> *I was thinking of our river by our place and thought it interesting how if a tree is hanging over the stream and into the water, it will go around the tree and not through.*

Stephen told the class:

> *Well, we've got a river by our place and if there's a tree sort of hanging off the bank and into the river, which you could use as an example of the light bulb, the current instead of going through and underneath all the branches the current will divert and go around the tree, then continue on its course.*

The other learners listened to this statement, but did not take it any further. For the fourth recorded time, a scientifically interesting analogy emerged.

Another learner, Rowan, was noticed searching through a textbook available for Form 4 science (but not used at any stage in this programme). He reported that he had found out what electricity was:

> *It's just excited electrons going around creating heat.*

Rowan said that he had found this out by asking his father, and that he was looking up the book to confirm that explanation. He had tried to fit this idea alongside the other one which had dominated in this class.

> *I've tried to work it out for the trucks. If you went along a winding road, its much harder. But if you went on a straight road its easier to heat up, so the power just goes along to the switch. It's much quicker to heat up S1 than it is to heat up L1.*

The teacher discussed with Rowan his evidence for the heating idea he had used in making this explanation, and further questions and investigations were proposed about heat in wires which the teacher asked Rowan to think about.

In another discussion, where a carrier model had been used to explain energy transfer at the bulb, the analogy was extended to try to account for the propulsion of the carriers.

Simon	*Then where do they get the energy to go back to the battery?*
Ian	*Maybe they've got a reserve supply like a car.*
Darrin	*How does that explain having two lamps* (in series)?
Ian	*Do those little particles or whatever go through the bulb or do they just drop it off and jump over, or something?*
Scott	*Those things in there, they don't actually carry energy but they are the energy.*
Teacher	*How does that fit with the idea that we use up energy?*

Scott *Well, each bulb doesn't actually use up energy but it causes heat or light, as those things have been forced through the bulb.*

This notion, similar to a friction model reported by Steinberg (1985) and favoured by scientists, was the fifth recorded situation in which a scientifically interesting idea or statement had been produced by these learners. Another learner responded to Simon's question (as the two bulbs problem was uppermost in his mind, too) with an anthropomorphic explanation which showed a consumption model for resistance.

Matthew *Perhaps those things are like people. They can keep going without food. They drop off their supply like its a hat or something. They just drop it off and keep walking. So, if there's more than one light, maybe they pick up more supplies at the battery.*

The teacher said that it was clear to him that, of the analogies examined by his learners, the moving particles model was dominant. He said he would promote the further development of this model; if a flowing water model had gained wide acceptance he would have helped his pupils to examine that model further.

<u>Developing a moving particles analogy.</u> One example of this development occurred when a group was attempting to understand the instantaneous response of a light bulb when a current is turned on.

Nicholas G. *I think the little particles are attracted to the low energy... its sort of like osmosis, they stay in the wire. And so the next time you connect it, and if you've got two light bulbs in a line, they're still in the wire, so that when it's turned on the battery sort of gives them a kick and they just move into both light bulbs at the same time.*

Learner *Well if that is so, then how come that if you get two completely different wires and connect them up, how come they go on automatically?*

Ross C. *They'd still run out on the other wire, because if the battery gives a kick, it'll give it a kick and they'd still be going.*

Stephen H. *But if they get a kick from the battery the ones that get out, there's still more from the battery being replaced back into it.*

Nicholas G. *Some elements conduct electricity, so it's probably just the atoms, there's nothing moving or anything. It's just that atoms get electrical charge.*

Nigel C. *I don't reckon that's right, because if you just get a brand new coil of wire and wire it up, it'll still come on at the same time. That's why wood doesn't conduct electricity, because of the atoms. The atoms in metal are much more susceptible to being charged up by electricity. That's how you get magnets, you charge up a lodestone and it goes electromagnetic.*

Peter *Back to what Stephen said: If he said that they stay in the wires after it's turned off, then if you connected it around the other way...how do they get back?*

Ross W. *No, I don't think they drop off all their energy at the light.*

Simon O. *But when the battery's just running down on its last energies, then it'll have no energies for them to get back.*

Teacher *Could there be a difference between the energy that makes them move, and the energy they carry?*

Simon O. *Could there be any difference? I don't know.*

Teacher *If we take Ross's trucks carrying coal, which is the source of energy, but it's not that coal which makes the truck go, is it?*

These learners, now engaged and confident in their use of an analogy, were able to argue through to a rational conclusion.

The discussion continued on the theme of how the electroparticles would circulate. A typical response was:

Richard C. *A person walks to something, he's using up his own energy, so he's just carrying other energy, so once he's dumped it off, he's still got his own energy to walk back.*

But the electroparticle model did not meet with total approval:

Jason M. *What about in a wire, it might be like a river, and its flowing? They automatically flow... like a log that has fallen into the river.*

While others tried to refine their electroparticle model:

Peter S. *The particles are in a row (line), and they just load it up as they pass through it, so they use the energy as they pass through, and then go back, but they keep in a row, so it keeps on going...*

Chris. *Maybe the only reason they do drop it off at the light bulb is because they're carrying those energy packets around, whatever they are, and they get pretty heavy. Maybe that's the only reason they drop it off.*

Stephen H. *About being bumper-to-bumper, that might explain why two lights go on simultaneously, because they're bumper to bumper...Well, we all wanted to know the other day why lights went on at the same time when you turned the switch on. Well, Chris said that these little particles might be bumper to bumper, carrying the energy.*

At the chalkboard, Stephen H. presented a diagram of his explanation to the full class.

Stephen H. *I said that they're all bumper to bumper, so just imagine a whole lot of circles like that sort of bumping into each other, going around. And Ross said "What happens when you take your wire off one end and it's still connected to the battery at the other end?" They'll still be getting a kick from the battery, and the other ones will be going out*

	into space. But if one is kicked out here, the one from the battery that kicked it out into there has got room to come in up the top. So that means your wire's still full. So, whenever you took it off, it'll still be full.
Interjector	*But they'd be facing around the wrong way.*
Stephen H.	*But who said they can only go one way? They might go...both ways.*
Nicholas G.	*If you just hook one wire up to the battery, it doesn't waste the battery. If you just hook one wire up like that and one gives a kick, the other one comes out, that's wasting. The wire has to be on both terminals.*
Teacher	*That's a powerful argument for the "pushing-out theory". It sounds, from Nicholas's argument, that it has got to be able to come back as well. It sounds to me that what Stephen is trying to tell us is that these are bumper to bumper, as he said, and its very much like a hose pipe that's full of water. As soon as you push some more water in one end, the water comes out the other.*
Learner	*And its still full.*
Ross S.	*What happens if you connect another battery to those wires? Will it have too many electrons?*

These learners have constructed a model for conductors with mobile electrons which scientists explain as conduction-band electrons. The teacher's involvement served to identify another facet of the analogy which he knew would help to extend the explanatory power of the model.

Further development. The teacher displayed by projector a three-cells-in-series picture (Figure 6.7), and commented that in it the cells did not supply the electroparticles, they supply the load that was being carried.

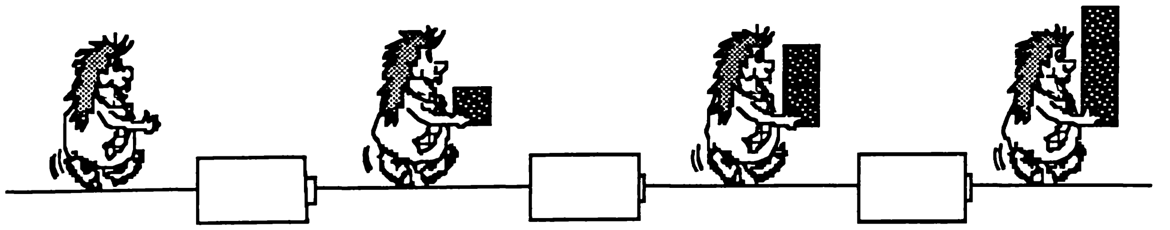

Figure 6.7: An electroparticle analogy for three cells in series.

The discussion came to a close at the end of this fifth period with these comments:

Jason	*I don't think you need those little things at all. Because you know how the thing only works if its conducting, the energy might just pass along it, passing it along.*
Matthew	*They just give a kick and they fly out so if you have a battery and one wire connected up and you just leave it like that, the battery would run flat. Maybe the wire is made with electroparticles in them naturally. You know, like it might be magnetic charge or something that all steel gets, or metal gets. And they just go in naturally. And when they are hooked up to a battery they just grab the power and do their job.*
Ian	*Maybe when the wires are rigged up to the battery, both of them, they act as a conveyor belt for the energy. It just sort of drifts the energy along from the battery.*
Jason	*If they are packed bumper to bumper, that takes away the idea that they are particles, because they're all joined together, so it might be just one long piece of string. Its all joined together, like a train.*
Teacher	*So are you saying all you have to do is move one and you've the lot?*
Learners	*Yes.*

Comment. Day Five had produced intense and sustained discussion on models for electric current. Learners had linked explanations to observations, they had made predictions from the emergent analogy, and tested those predictions logically and experimentally. Immediately after the concluding lesson in the challenge phase the teacher commented to the researcher:

> *The thing that impresses me is how far they have come. They now talk about things in terms of what they know and what they have seen happen rather than (vague ideas) like 'well it might be.' They are automatically sieving out what does not fit with what they have seen. And they are only accepting and hanging on to what they see. They just automatically sieve out what is ridiculous. And only ideas which might be right are accepted and tossed around. They are not interested in me telling them anymore. They have moved right away from what's the right answer?' When I drew something on the chalkboard I would get five or six people bursting to tell me what they think, knowing full well that I'm not going to say 'good', 'bad', or 'indifferent'. They just want to tell me. And what they really want from me is for me to say is 'that sounds like a good idea' or 'what if this was tried?' And they go off and think. They are not interested in whether you think it is right or wrong, or it does not appear to be so.*

This point was verified by Gauld (1986), in his interviews of 14 of these learners three months later. He asked if they knew what the teacher's view on electric current was. No one could tell him. Typical responses on this point, recounted by Gauld were:

Stephen H.	(Teacher's) *views..um..no I don't (know)..can't really remember his views.*
Interviewer	*Did he tell you them, do you think?*
Stephen H.	*No.*
Interviewer	*Have you forgotten?*
Stephen H.	*He...sort of ...made us make ...the discoveries. He didn't tell us if they were wrong or not but he just guided us.*
Interviewer	*Well, do you know what scientists would think about the electricity in that circuit?*
Stephen H.	*No.*

In another interview

Interviewer	*What view do you think (the teacher) has about the electricity in that circuit?*
Ian J.	*I don't know...I can't remember.*
Interviewer	*Did he tell you, do you think?*
Ian J.	*Yes. I think he told us.*
Interviewer	*And what about scientists who might study electricity...(what) view do you think they might have about that circuit?*
Ian J.	*Probably flowing equal in both wires.*
Interviewer	*Like your model?*
Ian J.	*Yes.*

With a similar commentary from another learner

Interviewer	*Do you know what idea (the teacher) has about electricity?*
Nigel T.	*No, he didn't tell us.*
Interviewer	*Well, how did you learn all this?*
Nigel T.	*With our own ideas and just with experiments.*
Interview	*And did everybody agree in the end?*
Nigel T.	*No.*
Interviewer	*They didn't? That's interesting. Didn't the experiments prove..?*
Nigel T.	*They all knew it was right but they didn't believe it!*

Ian J. told the interviewer about how he thought the class was operating

Ian J.	*(The teacher) let us experiment for ourselves.*

Discussions With The Teacher

Teacher's intentions. The teacher's stated intentions were:

1. To ensure that as many learners as possible should finish up with a model, an idea or a way of thinking about electric current that worked for them, and that they were happy with it.
2. To be concerned with one aspect only of electricity, namely the movement of charges, and to put aside the matters of energy and resistance for the time being.
3. To be a subtle guide through the topic, rather than a transmitter of other people's explanations.
4. To provide each learner with experience of a critical experiment that had been formulated by the learner himself. Such situations would be recognised by statements like *it's either this, or it's that,* or *if it is like this, then that will happen.*
5. To avoid mathematical treatment in the first stages of dealing with this concept, for in his experience *learners operate the numbers mechanically, (getting) the maths right, and they still haven't got the idea of what's happening to the circuit.*

What the teacher said he did through the challenge phase. The teacher considered that he:

1. Consciously refrained from direct intervention when he was asked by a learner to comment on an idea or question. Rather, he claimed that he deflected their requests to be told his view by folding questions back on to the learner with such requests as *Fine; test it, try it another way, and see if it holds up in other situations.*
2. Followed the direction that the class took in dealing with the models. *In other classes* (the researcher had pointed out) *they've all gone for model C. Here, my class went for model B. That might seem a small point, but the direction you go from there might be different.*
3. Identified the points which might cause the greatest learning problems, and tried to ensure that they were dealt with thoroughly. For example:

Researcher	*You could see a problem coming up with model B, the dominant model in this class, through the meter information. Do you think you solved that problem?*
Teacher	*No, I don't think so at all. That's one of the big hang-ups, that particular problem. For a few in the class the directions in a positive and negative sense is O.K. For others it is probably a fiddle. I think that was unsatisfactory...*

On the learning. The teacher thought that:

1. The important idea in generating an analogy came from within the class where it had been introduced by one person initially.
2. The demand to be told an answer gradually faded as the learners came to accept that the teacher was not playing a game in which the truth was to be revealed later.

3. A few learners loafed, but the general performance was excellent, and most learners enjoyed what they were doing.
4. The learners came to accept that this learning process was one of stating or identifying a point of view, then refining it by examining its implications, or by what they could do with it.
5. That several times he was approached outside of the class by small groups of learners who would seek his response to their (new) ideas, and that this was extremely unusual behaviour.

Outcomes. He noticed that:

1. These learners were becoming independent and confident after an unsure start to the unit.
2. It seemed as if the learners had recognised that the usual rules of teaching and learning science had changed here.
3. Some discussions kept going for unusually long times, and that learners had remarked that this style of learning was like that which they had in English (where that teacher was known to promote learner-initiated discussions), and that they enjoyed doing science this way.

Anxieties. The first of these had now been settled:

1. Until the fourth day of this challenge phase he had been concerned with the apparent slow rate of progress, for he said

   (I was) getting a bit concerned. But I was quite impressed today, as I went around and talked to quite a number ... their ideas are getting more and more clear, to them. And more and more towards what I would call a sensible concept. But had I not been able to detect that, I would have been worried.

The second had not:

2. The issue was one of knowing how to measure successful learning not so much in how he would recognise this, but how he would describe to his colleagues the learning that had taken place compared to the learning which took place in their lessons on electric current.

On what he would need to do next. His next task, he thought, would be to continue with this topic, so that the learners 'would see where it would end up', rather than to change topics completely. There were practical situations which he mentioned, such as working out the circuitry in the school's fire alarms (which could be activated from any one of a number of locations around the school).

On his 'long-range' thoughts. The teacher considered the implications for his, and others', teaching of other topics if an approach similar to this one was to be adopted. His views were that:

1. A novice teacher might struggle with this approach if the matter of classroom control and discipline had not been established.

2. There might be merit in explaining to learners why he had presented this unit in this way. (Other learners from different classes would have followed a different programme, and the two would be compared).
3. There were some conflicting thoughts about timing through the five lessons to this stage. At one time he had considered it a nuisance that the class would not meet again for two whole days, as the learners were at a peak (from which he feared they might slip down in the ensuing interval). Later he recognised that this was a time of appraisal and change, for the learners returned from the two-day interval with further ideas, often different from those with which they had left. He called this a "simmering" period, in which ideas were "mulled" over.

Other points. The researcher noted that:

1. Textbooks were not used by this class, although one was available.
2. The learners used ammeters in the challenge stage in a matter-of-fact way, without any strain or confusion, but that the information they provided in the critical experiment caused consternation for some (whose predictions had not been confirmed).
3. Although there were some learners who were non-participants, (three or four people), they did not distract the main group. The majority were highly animated, they held vigorous arguments, and there was perceptive listening in discussions where the points of difference were subtle.

Surveys from this Class

A survey was conducted ten days after the challenge phase had concluded, and it was repeated 66 days later. The survey (Appendix 4.2) contained three questions which were designed to probe respondents' views on electric current (questions 6, 7 and 9). The responses to these questions on the two dates are listed in Table 6.5.

Table 6.5: Selected responses from two surveys, compared with the view held before the critical experiment.

name	before view	April results Q6	Q7	Q9	model	July results Q6	Q7	Q9	model
Andrew P.	abs	nc	circ	nc	C	nc	circ	nc	C
Phil W.	C	nc	circ	nc	C	nc	clas	nc	C/B
Grant R.	C	nc	circ	nc	C	nc	circ	nc	C/B
Rowan C.	D	c	circ	c	D	nc	circ	nc	D
Aaron B.	B	c	circ	c	D	c	circ	c	D
Matthew W.	B	c	circ	c	D	c	circ	c	D
Ian J.	C	nc	circ	nc	C	c	circ	c	D
Ross C.	B	c	circ	nc	C/D	c	circ	c	D
Chris. W.	B	nc	circ	nc	C	nc	circ	c	C
Jason M.	B	nc	circ	nc	C	c	circ	c	D
Nick G.	B	c	circ	nc	C/D	c	circ	c	D
Stephen H.	C	c	circ	c	D	c	circ	c	D
Peter S.	D	nc	circ	c	C/D	nc	not	nc	A/C
Nigel T.	abs	c	circ	c	D	c	circ	c	D
Neville M.	abs	c	circ	c	D	c	circ	c	D
Sean L.	C	c	circ	c	D	nc	circ	c	C/D
Richard G.	C	nc	circ	c	C	c	circ	c	D
Jason B.	B	nc	circ	nc	C	c	circ	c	D
Dean A.	C	c	circ	c	D	c	circ	c	D
Arvind M.	D	c	circ	c	D	c	circ	c	D
Darrin W.	B	nc	clas	nc	B/C	nc	not	nc	A/C
Brian K.	B	nc	clas	nc	B	abs	abs	abs	abs
Nick F.	B	c	circ	c	D	c	circ	c	C/D
Ashley D.	B	nc	circ	nc	C	nc	circ	nc	C
David B.	B	nc	circ	nc	C	nc	circ	nc	C
Simon O.	B	c	circ	c	D	c	circ	nc	C/D
Aaron S.	D	nc	clas	nc	B	nc	circ	0	B/C
Ben B.	B	c	circ	nc	C/D	c	na	na	D?
Antony S.	B	c	circ	nc	C/D	c	circ	nc	C/D
Richard D.	B	nc	not	nc	A	nc	not	c	A/D
Ross W.	D	c	circ	c	D	c	circ	c	D

Key A, B, C and D identify model A,B,C and D respectively.
c = current is conserved
nc = current is not conserved
circ = current is circulating
clas = currents clash
not = current is not circulating nor clashing
abs = learner absent from class.

From Table 6.5, nine learners (Rowan, Aaron, Matthew, Stephen, Nigel, Neville, Dean, Arvind and Ross W.) identified with model D in the first post-survey and made the same selection ten weeks later. Six who selected model C in April (Ian, Ross C., Jason M., Nick, Richard and Jason B.) had changed to model D in July. Three who selected the model D responses in the first post-test indicated a different model ten weeks later (Sean, Nick and Simon). At ten weeks 15 out of 32 identified the model indicated by their classroom experiments and debates. Of the remaining learners seven retained a model C view from the first post-test to the second post-test. This was the lowest regression effect noted in any of the trials.

There has been much change and de-stabilizing of ideas. Learners recognised the characteristics of model D, in which current is conserved, and may accept it logically while still retaining personal links to other ideas which agree with their own "common sense". That 15 out of 31 learners used a conservation model for current might be a satisfactory position if this was a long-term change.

Longer-Term Stability: An Independent Study

Longer-term changes in learners' views were studied by an another researcher (Gauld, 1986). This investigator was unknown to the teacher and learners, and he had not been previously involved with the research. 14 learners from this class were interviewed 2-3 months after the teaching. The data on representations of electric current elicited in these interviews is summarised in Table 6.6, together with the views obtained by earlier surveys.

Table 6.6: Models of electric current selected by a sample of learners.

method of response date name of learner	direct 3 April	survey 26 April	survey 2 July	interview August
Phil. W.	C	C	C/B	C/K
Grant R.	C	C	C	B-C-C/K
Aaron B.	B	D	D	A/K
Ian J.	C	C	D	B
Ross C.	B	C/D	D	A/K
Jason M.	B	C	D	D-C-C/K
Stephen H.	C	D	D	D-A/K
Nigel T.	abs	D	D	D
Richard C.	C	C	D	A/K
Jason B.	B	C	D	A/K
Darrin W.	B	B/C	A/C	B
David B.	B	C	C	C
Simon O.	B	D	C/D	A/K
Antony S.	B	C/D	C/D	A/K

Key 'Direct' indicates that learners identified which of the four models A, B, C and D best represented their view of electric current.
A/K and C/K represent variations on these models which the learners had constructed for themselves.
'Survey' refers to the ten-point survey administered earlier, and quoted in Table 6.4.
'Interview' indicates that this selection of a model came from the independent investigator's interview with that learner.
'abs' indicates that a learner was unavailable for a particular survey.

Gauld's (1986) summary of the responses follows.

1. *Although others had pointed out that learners' ideas are resistant to change, some changes had occurred.*
2. *There had been little, if any regression of the type reported earlier by Cosgrove, Osborne and Carr (1985a). He thought that this may have been because the context had been so enriched or enlarged that the original idea was no longer attractive. Learners could now use a wide range of arguments for and against any proposition or mechanism.*
3. *These learners interpreted the movement of charges in terms of what they thought the mechanism was by which a bulb glowed, and that a carrier model was a consequence of a consumption or reaction process (whereas the scientist's model, D, is more likely to be developed through a friction or squeezing process).*
4. *The learners had become aware of others' explanations.*
5. *Those who had not adopted the majority view had retained their integrity.*
6. *Rather than making statements of assured belief the learners seemed to 'try out the options in the light of the evidence.'*

One Year Later

An Action-Research Project with Form 5 Learners

The situation. The package was tried at the Form 5 level to see if it would be helpful for learners whose ages were 15 - 16 years. Modifications were made in the challenge phase by introducing the trucks analogy as a development suggested in this school in the previous year, followed by detailed study of circuits A and B (Figures 6.2 and 6.3) in terms of this analogy.

The teacher of the Form 4 class described in the previous section presented this electric current teaching package to three Form 5 classes as a two-week introduction to a four-week module on electricity one year after the trial reported earlier in this chapter. The teacher's purpose was to clarify the concept of electric current. The researcher observed most of these lessons.

These classes, named 5.1, 5.2 and 5.4, were considered to be a cross-section of Form 5 learners. Class 5.1 contained a group of four boys considered to be students of the highest ability and promise. Of the previous year's Form 4 class, 11 were present in this sample of 75 learners.

The teacher surveyed these Form 5 classes at the end of the teaching using the ten-question survey (Appendix 4.2). A class of 20 Form 6 physics learners (people who had succeeded in the school certificate examination at the end of the previous year and who had elected to study physics) was also surveyed as a pre-test before they commenced the electricity topics at that level. These older learners had not been taught in the manner of this teaching package when in Form 5.

The data. The survey data for classes 5.1, 5.2 and 5.3 are reported in Appendices 6.1, 6.2 and 6.3. Analysis of this information has produced the summary presented in Table 6.7 together with that for the Form 6 physics class.

Table 6.7: Form 5 and 6 learners' survey information.

Class code (Form)	number of learners	mean score (max. = 20)	number with model D	number with score > 15
5.1	34	18.3	32	31
5.2	25	17.4	23	18
5.4	16	17.7	15	13
6	20	11.4	1	0.

Form 5 learners. Of the 75 Form 5 learners, 70 (89%) recognised that electric current was conserved by answering questions 6, 7 and 9 in ways that were consistent with that view. The mean score in the survey was 17.8 (89%), the standard deviation 2.54 (12.7%). Thus, 83% of this sample scored 76% or more. With this small spread, the gap between high-ability and low-ability learners was narrower than in normal testing. Typically, topic tests produce a mean of 55-60%, with a standard deviation of 20% (i.e. about 80% would score less than 76%).

Form 6 learners. Learners one year older who had elected to study physics in Form 6 and who had not been given this package in Form 5 were unable to recognise the current-is-circulating-and-conserved principle in the survey items. They expected electric current to behave differently because almost all (19 out of 20) identified a non-conserving view.

Previous year's sample. Of the 11 learners who had been in the previous year's investigation, ten responded with model D, and the other learner indicated a mixed C/D set of responses, as he had done in the previous year. (This information is not in Table 6.7; these learners are identified by an asterisk beside their names in Appendices 6.1, 6.2 and 6.3).

Observations of attitudes. The teacher reported that:

1. Some elite learners (the group of four) stated that they did not enjoy this teaching and learning approach; the progress had been too slow for them, as all they needed was to be told the information from which they would be able to deduce all of the associated ideas (and the teacher agreed that they would be able to do this),
2. Most of the other learners (especially those in class 5.4 where academic competition was lowest) were at ease, natural and more interested in the development of their own ideas than in finding out the scientific answers.

The Research Questions Met In This Chapter

Three questions have been addressed in this examination of learning in the challenge phase.

Question 3: **Does The Problem-Solving Orientation Of Technology Provide The Desired Environment In Which To Learn This Concept?**

In this case study the familiarisation phase of four one-hour periods involved the learners in seeking solutions to some technological problems. In these periods the pre-dominant strategy was the learners inventing circuits which they thought would solve a problem, and then improving them through critical evaluation and experimental testing. The teacher's stance was to focus learners' thinking about the central concept by asking questions about the solutions found and to deflect requests for answers when he considered that the learners would be able to make the steps themselves.

In the challenge phase that followed some of these learners retained this problem-solving orientation in creating analogies of their own; all responded to their own or to others' analogies by critical analysis or testing of predictions derived from the analogies. Scientific habits resulted in refining a single analogy from all suggested analogies.

For some learners the problem solving activities were considered to be at least as valuable as the formation of views on electric current.

Question 5: **Is The Generation Of Analogies By Learners And The Consideration Of Others' Analogies An Effective Learning Strategy?**

This question has been clearly answered. These learners showed that they were capable of sustained and sophisticated reasoning in their refining of the two-component analogy introduced by one of them. As well, there were occasions when ideas emerged which could have been used to develop other concepts associated with electricity. Included in these were notions of resistance ("the electricity is scared of getting red hot", a river, a friction model, and "it just sort of drifts the energy along from the battery"). The transcripts presented in this chapter indicate nine such events in which other electrical ideas were proposed by these learners.

By the fifth day of this extended challenge phase some of these learners hinted that they were moving on past this two-component approach, towards a "pulse" model demonstrated by a ring of people holding hands and sending a message in a clockwise direction by squeezing the hand of a neighbour on the left after the right hand had felt a squeeze.

Question 6: **Do Transitional Frameworks Assist Learning Electric Current?**

This question is linked to a fundamental purpose of science education, that of helping learners make better sense of the world. In particular, it asks about the outcomes for learners who traditionally do not succeed in science (the "80%" mentioned by Fensham (1985)).

From this package learners are offered chances to develop a model for electricity which can be regarded as satisfactory for everyday life. Through it they can make sense of open and closed circuits, batteries going flat, why they get power bills, why two bulbs in parallel glow as brightly as a single bulb, why two bulbs in series glow less but equally brightly, etc. These learners have the opportunity to continue to consider the limitations of the particular transitional framework they hold, to refine it by fine-tuning, or to place it alongside other analogies for comparison. It is possible that this development might continue to be driven by the learner, and thus need little or no further direct teaching.

This position in which a partial theory is devised initially is seen as being scientifically respectable. It is also educationally a satisfactory way of meeting the call of Papert (1980) and others for a serious consideration of ways of making science accessible to people.

Chapter 7

THE REMAINING RESEARCH QUESTIONS

This chapter deals with the five remaining research questions which can be best answered by considering the evidence from both chapters 5 and 6.

Questions About Technology And Science

Does This Approach Provide An Understanding Of The Relationship Between Science And Technology? (Question 4).

This question was not directly addressed in any of the data-gathering in this study, but there were some effects that bear on it.

1. The learners were not heard to say that what they did in this teaching package was not science.
2. No distinction was made between problem-solving to do with apparatus and that to do with ideas.
3. Incorporating real world situations that gained the learners' attention lead to them doing much effective thinking.

The outcome of this supports the view advanced in chapter 1 that science and technology can be seen as an entity, with little difference.

Does This Approach Provide Learners With An Understanding Of The Nature Of Science? (Question 8).

This question was also not formally addressed in the study, but insights into ways science has been portrayed in some of these schools were gained.

The 11 year-old learners in the first trial knew that they were studying science and accepted that this package was a way of doing that. They gained a working understanding of science as identified in chapter 2, by thinking things through and by experiencing open rather than closed problems.

The 14 year-old learners in the second trial had a different view of learning science and were uncomfortable with this approach. To them science was learned as knowledge. Learners in trials three, four and five indicated that there was something different about this approach. In trial four science was regarded by some learners as being a race to complete a set course of exercises.

In some cases, there was evidence that learners' and teachers' ideas about science were impediments to their entry to this approach. The learners in trial six accepted this approach as science learning.

Accessibility To Teachers

Is This Approach Accessible To Teachers?

Question 9 has been partly answered. Two teachers in these trials could operate it immediately (one of these being a remote teacher with no contact with the research group, the other being a former student of the researcher's). Another said that she would be able to teach this package having now seen it presented to a class. Two of the three teachers who took part in trial four (in a co-educational school) said that they needed to see somebody else teach the challenge phase first. There was a complete mismatch in trial five between the teacher's approach and that expected by the researcher. These outcomes indicate that the use of these materials by teachers is not straightforward. If they are to be available other than to particular teachers who have a specific understanding of, and sensitivity for, both the research base and the underlying philosophy and psychology then the problems reported in trials four and five will have to be offset. After the outcome of these trials it was decided that extensive teacher education would be necessary before the package was implemented.

In-Service Education Of Teachers

In one situation teachers were introduced to the package under research conditions; they worked through a portion of the package at a time with the researcher as facilitator, and then implemented that portion with their learners, over a period of weeks. An observer, Biddulph (1987), reported that these teachers:

1. Enjoyed using the package with their classes.
2. Claimed that they changed their views on what science is.
3. Preferred this sharply focussed topic to the broad approaches characteristic of the curriculum.
4. Considered that they were less under the control of others (such as curriculum advisers) and more in control of their own teaching.
5. Called this a learner-centred approach, and noted that learners' behaviours showed an unusually high degree of co-operation in sharing their ideas and accepting others' differing views.
6. Felt that learners were challenged to think, and to reach their own conclusions.
7. Said that they would try to transfer this teaching approach to other science topics.
8. Had worked hard and had been extremely busy in dealing with learners' questions, experiments and ideas.
9. Were unsure about how to evaluate learning in a non-normative approach such as this.

Pre-Service Teacher Education

Initially the researcher was reluctant to use this package in the pre-service education of secondary school teachers, because the opportunities for novice teachers to implement the package in conditions where they would receive the necessary professional support were thought to be not available. Secondary school teachers would not be expected to view favourably this way of teaching.

Primary teachers-in-training who typically have not been successful science learners bring with them views of science (based at least in part on their school experiences) which often portrays science as non-humanist and doctrinaire (Plimmer, 1981). These student-teachers give science very low priority when they make choices between it and other disciplines as subject studies (Clark and Vere-Jones, 1987), and, on becoming teachers, in their classroom action. Thus there was thought to be little to lose in trying this package with student-teachers.

The researcher's colleagues have used this electric current package in their introductory science curriculum courses for primary school teachers, to provide an alternative view of learning science. Some of the outcomes from these courses have been described by Biddulph (1988) who observed that student teachers:

1. Experienced an alternative mode of learning.
2. Began to recognise the real nature of science.
3. Appreciated how children actually learn, and how to facilitate that learning.
4. Gained confidence in the area of science generally.

Faire and Cosgrove (1986) reported similar outcomes and noted that the package had considerable appeal to Maori student-teachers.

When the gains noted by Biddulph in both studies are added to the successful outcomes learners exhibited, the position has become more optimistic; it is seen as providing a foundation course in science for student-teachers in which an alternative view of both science and learning can be presented.

Remaining Questions

What Does This Study Say About Curriculum Design? (Question 10).

A number of insights have been gained from these trials and from other research with this package.

1. The design is different from the standard way of dealing with this topic because here one theme, electric current, has been given a central position and other normally related topics have been treated peripherally (e.g. fuses) or not at all (e.g. electrostatics and electrolysis). This approach required the teacher to respond to learners' questions about non-central matters (such as electricity generation) by simple demonstrations and/or to introduce them as extra material (e.g. in dealing with the circuits for a car's flashing lights a switch based on a bi-metallic strip would be demonstrated).
2. This research has helped in clarifying the scope of electricity topics taught in Forms 1-4 These topics are now seen as being in three strands:

Making electricity	In which electromagnetic induction and pairs of metals are considered as principal sources of electricity. This focus avoids giving prominence to cells and batteries.
Delivering electricity	This type of package could be used to develop learners' ideas about current.
Controlling electricity	The notion of a resistor as a controller of the flow of electrical particles might help to deal with the notion that resistors consume something.

3. A place has been found for critical experiences as foci for learning. On the one hand these can be learner-designed tests to discriminate between alternatives (which Medawar (1984) called Galilean or critical experiments). Or they can be circuits which challenge learners' new views, as happened in trial six with circuits A and B.
4. Another view of curriculum balance can be advanced. Whereas this term has come to mean a blend of certain disciplines it can also be seen as a blend of teaching approaches. It might be possible, once or twice a year, to permit a science topic to run as long as it remains a profitable learning experience.

Does this approach shed light on what learners' can do?

There were many occasions noted where learners' explanations or analogies were noted to be close to scientific ideas. These included their ideas about resistance and energy, particularly the former. Most, but not all, of these instances occurred in the expanded challenge phase of trial six, and the conditions for learning that developed in that class may suggest what is required to allow these ideas to emerge.

Learners showed that they could solve problems without prior instruction about how to do this. Sometimes their solutions were elegant, occasionally they were exceptional for lateral thinking. The approach established here has opened up a scenario about problem solving which was unexpectedly rich, with sophistication, self-evaluation and penetration features of learners' strategies and outputs. It seems that the trick has been to establish a context in which learners can ramble about long enough for a problem to become a part of these learners' intellectual architecture. This notion of *penetration* can be considered alongside that of *engagement* in Piagetian terms, and Osborne and Wittrock's *attention* in their theory of generative learning.

Evidence had been accumulated from trials 1,2,3 and 4 which suggests that this technological context does engage female learners at least to the same extent as males. It is thought that developing the familiarisation phase in the way intended here can equalise the access to science for female learners.

Many of these learners can use a transitional framework when reasoning about electricity, whereas it is known that few can use the scientific framework.

Suggestions For Further Work

Further investigations could be made into a number of aspects of this topic.

Science Teaching

The varied reactions of teachers to this package suggest that it might be seen as an alternative approach for some teachers who are comfortable with it. For teachers who wish to try this, it is thought to be desirable for them to work alongside another who has successfully confronted the view of technology, the philosophy of science and of learning embedded in it. This approach to teacher education suggests that a study of the philosophies of science held by teachers might be a factor to be considered in curriculum reform. In a similar vein, teachers' psychologies of learning can be explored as they interact with the ideas on learning presented here as their pupils work through the package.

Assessment and Evaluation of Learning

Teachers comment that an impediment to their adoption of any new approaches to teaching and learning is in having to deal with existing methods of assessment, including external examinations, which are seen as being integrally linked to present methods of teaching. The problem may be one of reconciling a demand for a summative assessment in new conditions which are perceived to be less objective than teachers are used to. Such considerations do constrain teachers, and there is no evidence yet that learners taught electric current in this way do achieve higher results than others on traditional assessment instruments. While assessment reform is being encouraged, research is required into alternative modes of assessment.

Learners' Frameworks

There are aspects of children's frameworks for physical phenomena which are not understood, including the origins of these frameworks. When this study began, some researchers thought that the earliest ideas of learners would be of little consequence, and that research should start when these ideas become more sophisticated. Now this researcher's view is that these frameworks are based upon networks of schemata which young people build up as they attempt to interpret sensory information about themselves and their worlds. The anthropomorphic schemata (sometimes called 'phenomenological primitives' (Di Sessa, 1983)) were recognised in a related study from a six-year-old boy's ideas on electricity (Cosgrove, 1983; Appendix 3.3). In Claxton's terms, the initial gut science ideas about electricity might be able to be separated from later lay science ideas, and children's earlier, and earliest, schemata recognised.

Transitional Frameworks

The idea of transitional frameworks needs to be further studied within the topic of electricity and elsewhere, particularly with young learners, in order to investigate the value of further analogies, both learner-generated and imported which might help some learners to move from a two-component system to a single component system.

Electricity Topics in the Curriculum

A framework. Views have been developed on ways of presenting electricity topics in the curriculum. A framework for electricity has been devised (see Figure 7.1) in which the topic is presented in three strata, based on the following views:

1. Learners benefit from many experiences with electricity.
2. The concepts of current, resistance and electromotive force can be approached from thinking about domestic appliances and other technological devices and systems.
3. When learners are ready they can be helped to differentiate their ideas about current, resistance and e.m.f.

These three views represent the central purposes of three strata. The first is **experiencing**, in which learners become familiar and confident in operating simple electrical equipment. The second is in **nudging** learners to recognise that there are three effects controlling the events in electrical circuits and to begin thinking closely about them (through the question - based interactions and conversations of learners with learners and learners with teachers (Faire and Cosgrove, 1988)). The third stratum deals with **challenging** learners' ideas about current initially, and then resistance and electromotive force.

Packages for learning about resistance and e.m.f. have been designed (Cosgrove, 1984) and need to be investigated under research conditions.

Further technological approaches. The context of familiar technology has proved suitable for many learners. This approach could be extended by investigating the outcomes of designing the electricity curriculum around the technology of control, initially with switches as the central context. By considering mechanical, electro-mechanical and electronic switches, some of the ideas of electronics would be introduced to the curriculum. A teaching package with control technology at its centre and which built on this work would be expected to shed some light on learning electronics.

Science and Technology Education

There have been three thrusts linking science and technology in education:

1. The idea of technology as a probe of science learning which has been investigated elsewhere (see for example, Cosgrove, Newman and Forret, 1987; Dreyfus, 1987).
2. The investigation of learning science from applications (Jones, 1988).
3. Technology as a context for science learning (this study).

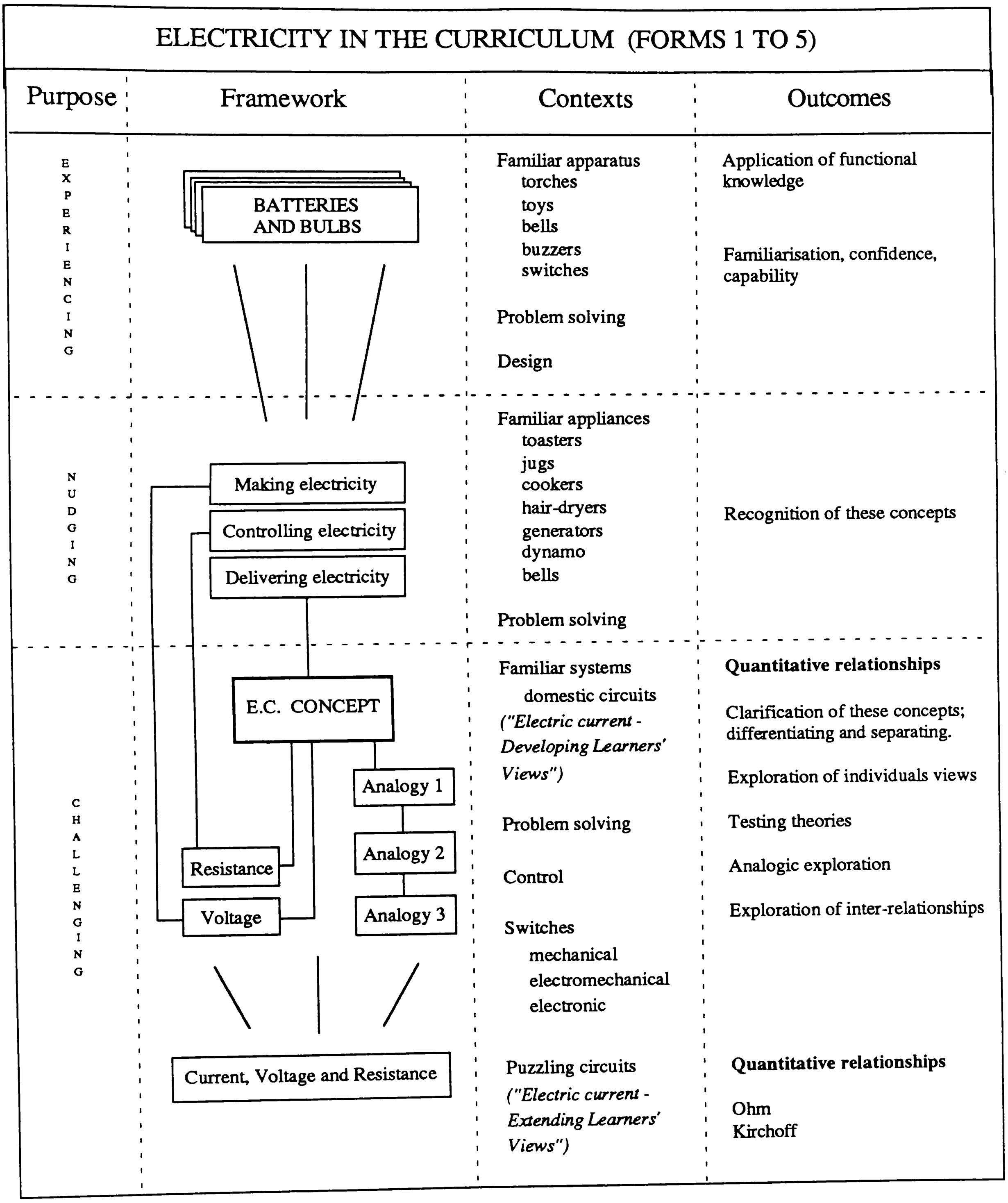

Figure 7.1: A framework for learning electricity.

These related studies could be examined for their common ground, and to attempt a synthesis of their outcomes and ideas.

Last Words

This thesis set out to describe the effects of teaching the topic of electric current within a technological context, and with a constructivist-developmentalist view of learning at its core. It has shown that for some learners and some teachers it can be an alternative to the traditional approaches to science teaching.

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APPENDICES

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Appendix 3.1

The official prescriptions for electricity in Forms 1 and 2, Forms 3 and 4, and Form 5.

Forms 1 and 2. Electrical energy

To develop ideas of electrical energy,its major sources, its conduction, its effects and uses. To involve students in the manipulation of simple electrical apparatus. (From the Form 1 - 4 Draft Syllabus, 1978, p.28).

Forms 3 and 4. Electrical Energy

To extend the knowledge of electricity gained (above); to introduce students to more complex circuits involving the use of meters; to introduce the moving charge model for conduction of electricity. (From the Forms 1 - 4 Draft Syllabus, 1978, p.46).

Form 5. Electrical Systems

Intent and Approach. Earlier work on circuitry is developed to provide familarity with a variety of circuit components, leading to simple relationships involving electrical quantities. The motor and generator effects are introduced.

1. Circuits. Properties of conductors and insulators in terms of moving charges. Behaviour of the following components in DC circuits - power, supply or cell, switch, resistor, variable resistor, diode, lamp, heating element, ammeter, voltmeter.
2. Voltage and current in a circuit. The voltage of a source considered as an indication of the difference in electrcal energy between one terminal taken as zero volts and the other terminal. The voltmeter considered as an instrument that samples and compares energy distribution around a circuit. Current considered as the rate of flow of charge, the direction of current flow to be taken as being from a position of high voltage to one of lower voltage.
3. Power. Energy dissipated by heating and lighting components. Rate of energy release as VI joules per second (watts).
4. Voltage-current relationships. Use of voltmeter and ammeter to study the relationship between the voltage across a conductor and the current through it. Definition of resistance. Qualitative effect of connecting resistors in series and parallel. Variation of resistance with temperature.
5. Electromagnetism. The presence of magnetic fields surrounding magnets and electric currents. The action of a magnetic field at right angles to a current in a conductor, and the resultant motion of the conductor. Thid interaction as the principle of operation of the direct current meter.
6. Electromagnetic induction. Induction of current in a complete circuit when a conductor is moved across a magnetic field. Idea of relative motions between field and conductor.(Education Gazette, 1984)

Appendix 3.2

A teacher's view of the way the middle level (Forms 3 - 4) electricity topic is developed.

The purpose seems to be to complete a Cook's Tour of a wide range of aspects of electricity within about four weeks, in which pupils are guided fairly swiftly through the content.
The content typically includes a review of atomic structure, electrostatics, conductors and insulators, current flow and circuits, measuring electric current and energy, making electricity (e.g. hydro generation), magnetism and electricity, electric motor and generator, electrical safety in the home, and first aid. The teaching methods are note taking, demonstrations and student pracicals.
This teacher (used as a curriculum consultant on this topic in the region) commented that, in his opinion, there was far too litle time to tackle all of these points. Much of the time was spent writing, the students had very limited (practical) experiences. The terminology was a problem because there were many new words and symbols, and learning them became a major part of the work. The students found this topic complicated abd difficult to understand, but the practicals were enjoyed.
There was much confusion because too many concepts were over-laid. The experiences were too brief and too shallow. Many of the new words were not understood. The demonstrations were often not clear or were not easily seen. Sometimes the presented right answer was not what the student saw happening in her or his experiment.
The numerical, quantitative approach was introduced too early. Students have heard many of the terms before the teaching and have their own views of what current and voltage are. Teachers are, more often that not, unsure of the content and the concepts.

Appendix 3.3

Transcript of an interview with a six-year-old about electricity.

MC Here's a....?
Boy Light bulb.
MC Tell me about them. Hold it in your hand.
Boy Well, um, they have a little animal in there. It's not moving, 'cos there's no little things, they're antennas or feelers.
MC Feelers? What are the feelers?
Boy They feel lightning together. It touches one, they do it together. They tell each other.
MC What's in there?
Boy A blue animal.
MC What colour is the animal?
Boy Green.
MC And what does the animal do?
Boy Um...
MC What does the animal do?
Boy It, ah, I don't know...it makes lightling(sic) and crashes together.
MC It makes lightning and crashes rogether?
Boy Yea. And then it um...it lights up. But it doesn't have the power right now to do it...
MC Where does it get the power from?
Boy I don't know...one won't do but two will (referring to batteries).
MC What's that you've got there?
Boy Where's another one?
MC What's it called?
Boy A battery. Hey, where's another battery?
MC One's enough!
Boy Will it work?
MC Make it work.
Boy Can I have some celotape?
MC We can use our fingers....What do you want to do there?
Boy I put it around that one around there, and I need another one (wire) and we put that one on there (pointing to the terminals of the battery).
MC Well, let's just jam it on then see what happens.
Boy Can you hold one? Now...
MC It doesn't seem to be going...
Boy Maybe that animal is dead.

MC What do you mean "that animal's dead?"

Boy Well, um, we'll die soon, and they die soon.

MC What does "die" mean?

Boy Can I put it here, on that bit there?

MC That's nice. No good?....Try this one.

Boy These round ones? (a slightly different type of bulb).

MC Mm. Does that go?

Boy It looks like it. It goes like this. I heard it, on the thing (TV?).

MC And what about that (the bulb glowing)? What do you think there now?

Boy It's great. You know, when you have it in a torch this takes all the power and that's it.

MC Did the bulb go?

Boy Only if you do that, it won't go.

MC Does it go? Has it got an animal in it?

Boy Yes.

MC What colour is it?

Boy Green I said.

MC Let's have a look.

Boy See, you can see the green part.

MC No...oh yes, I can.

Boy That's the metal part.

MC And what else has the animal got?

Boy These things for standing it up. Stand one there...and one here.

MC Let's see if that one here has got anything in it. (Shows the boy another bulb). Oh, that one goes well, doesn't it? That's a nice one. Let's put that one there, because that goes.

Boy Yea, that's a good one.

MC What do you say about the animal in there, then?

Boy It's green. Because they're the same kind of animals. But they're in a different coloured cage.

MC A different kind of cage. Right. Does that want to go?

Boy ...It'll make a light in your hand....

MC Is it going?

Boy Oh, yea, but I forget to put it on that grey bit.

MC Well, what's the animal doing when the light's on?

Boy Making, crashing, light.

MC Making?

Boy Light.

MC How does it make light?

Boy	I don't know...
MC	It does doesn't it, because we can see it. How does it make it?
Boy	Oh, it just crashes the lightning together.
MC	And what about this one? Where the animal won't make light. What do you say about that?
Boy	Well, the animal's dead.
MC	The animal's dead...?
Boy	Yea...'cos we die, well that dies.
MC	That's interesting, isn't it?
Boy	But if it's an alive one, and crash it, it's dead. And if you put the glass together, it won't go. "Cos these will go flat out, like that.
MC	You talked about a cage before. Can you remember that?
Boy	Well, they have a glass cage.
MC	A glass cage?
Boy	So I can see, and they make the light, they die.
MC	Do you know anything more about lights?
Boy	Yes.
MC	Tell me what you know.
Boy	Well...when...a torch switches it off, the light off, well that's the thing is actually moving down, so it won't touch it.
MC	How do you know that?
Boy	'Cos when you press that it goes, it falls down, like that.
MC	Where did you learn about animals?
Boy	I watched...I can't remember when I heard about it.
MC	Did the teacher tell you?
Boy	I can't remember.
MC	Did the television tell you?
Boy	Ah, yea, on.....
MC	"That's Incredible?"
Boy	No.
MC	What?
Boy	Well...um..from...ah...what's the one with Mark, Tony and Lisa?
MC	No, I don't know.
Boy	The Television Workshop.
MC	"3-2-1 Contact?"
Boy	Yea. I learnt it from that.
MC	Do you know 'what'?
Boy	What?
MC	I don't think there's an animal in there.

Boy What?
MC There's not a green one in there.
Boy Oh...these ones are dead...that means they have a green one. This one's white.
MC That one's not dead,its got a green one.
Boy No, its got a black one.
MC No, its sort of greeny-black.
Boy You know, its died sort of, you know, its going to die soon.
MC How do you know?
Boy Because its showing it. Sort of bending and all that.
MC Do you know what?
Boy What?
MC I don't think there's an animal in there.
Boy What do you think?
MC Well, I don't think there's an animal in there. Who feeds it?
Boy Well, it feeds on its power.
MC Oh, what power?
Boy You know, how they make lightning.
MC You tell me.
Boy By power, of course.
MC Where does the power come from?
Boy The battery.
MC Well, you've got it worked out, haven't you?
Boy Yes.
(later)
MC Are you sure there's an animal in there?
Boy What do you think? Do you think there's an animal in there?
MC No.
Boy Well how come, ha ha ha?
MC Well I'd want to know how it got in there.
Boy When they made it. People made it.
MC Who put the animal in? How do they get in there?
Boy The glass wasn't on, and they put it in, then they put it on.
MC When the glass wasn't on?
Boy Yes.
MC I see.

ELECTRIC CURRENT

DEVELOPING LEARNERS' VIEWS

TEACHERS' GUIDE

Hamilton

ELECTRIC CURRENT - DEVELOPING LEARNERS' VIEWS

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APPENDIX 46

ELECTRIC CURRENT SURVEY

1.1 THE MATERIALS

This teaching unit has been devised in order to help teachers and students develop their concepts for electric current. There are six parts to this unit,

- This Teachers' Guide,
- A Student's Workbook,
- A set of OHP presentations of circuits and analogies,
- A video for teachers,
- A computer-based circuit simulation (BBC & Apple IIc)
- A water model, using a pump and flow-watchers.

Each of these is available separately.

1.2 ACKNOWLEDGEMENTS

The ideas contained in these components have come from many sources. Where possible, we have acknowledged them. The teachers and researchers in the Learning in Science Project action-research programme on electric current contributed to, and commented critically, on these ideas. Alister Riddell provided the stimulus to develop a set of problem-orientated circuits. Lyn Skilling developed an interesting simulation for circuits and provoked our thinking about analogies. Many students in intermediate and secondary schools in Hamilton have helped in refining these materials. We thank these people for their comment, co-operation and assistance.

1.3 INTRODUCTION

Electricity topics have been a troublesome part of school science teaching. Recent research effort, in New Zealand and overseas, has been brought to bear on these topics and their underlying concepts. We have formed some insights into this problem, and now we are working towards more effective ways of teaching the fundamental concept of electric current. We believe that if this concept is clarified and taught in a way that enables youngsters to *get to grips with it*, then the source of much of the difficulty may be removed.

Our investigative strategy has been to find out the views children have formed in their attempts to make sense of their worlds. We talked to many hundreds of children individually about a series of natural phenomena and events. We found that children do have views on most scientifically interesting effects, and these include the notion of electric current. The views which children have formed (sometimes described as children's science, alternative frameworks and mini-theories), do help them to make sense of their world. Unfortunately, when learning physics, it is rare for children's views to coincide with the modern scientific view. This mismatch is one reason why many children have difficulty with electricity topics, and with science in general. Another is because many children not only have their own views of electric current but these views are strongly held, and often resistant to modification.

Some teachers assume that children's heads are empty of ideas about scientific events, and they believe that their role is to transmit the scientist's view. We doubt the chance of success for this method of developing scientific concepts. Perhaps there are a few children who do not mind being told the scientist's view to explain events, but for many learners, an exposition of the scientist's view, no matter how lucidly it is made, is not enough, by itself, for them to adopt this as their view. This may be because the scientist's explanation does not make sense to them. Seymour Papert gives a refreshing insight into the problems learners have with formal physics. He writes

> "Certainly very few students are able to integrate formal physics knowledge with their intuitive sense of physical process."

Papert thinks this is because

> "It seems to be nobody's business to think in a fundamental way about science in relation to the way people think and learn it."
> (Mindstorms, p. 188)

We wish to change this state of affairs by seeking effective stepping stones to the successful learning of formal physics. We need to find things in the mental world of the learner which will help him or her to personally reconstruct the laws of physics. Unless we do, the learner will strain to make sense of the physicist's view of the world, because

> *The learner does not know anything else like these explanations which he or she can relate to them.*

Formal physics contradicts much of the learner's immediate experience of how the world works, and he or she lacks the ideas needed to construct a completely new view of the world.

The (usually) passive mode of learning in science means the new knowledge cannot be exercised in a personally involved and motivated way; nor can it be assimilated into everyday experience.

The teacher's task is to remove the sources of these strains. If they are not removed, then many learners will not be able to use the scientist's view, preferring instead to retain their own ways of understanding the world.

Another situation which can prevent children from fully understanding the concept of electric current exists when the teacher does not clearly understand the scientist's view. If this is the case, then the chances of children finding it are even more remote. There is sound evidence to substantiate the belief that some teachers have difficulty with the concept of electric current. At a teacher education college in the U.K. a colleague found that 39% of a class of physics graduates did not hold the scientific view of electric current, and in a similar group of biology and mathematics graduates 45% did not have this view. Helping teachers to clarify their views on electric current is a major reason for undertaking the research which has led to the preparation of this teaching unit on electric current.

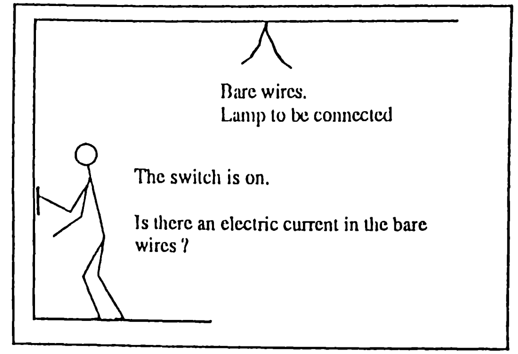
1.4 CLARIFYING THE TEACHER'S VIEW OF ELECTRIC CURRENT

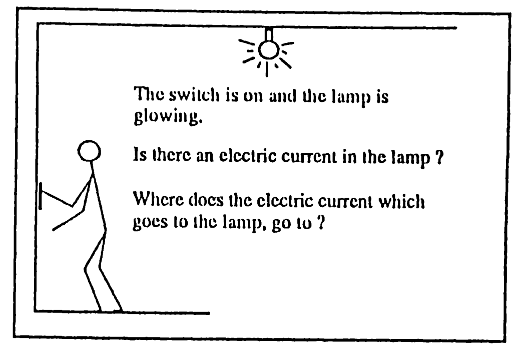
At this point it would be a useful exercise for you to write down how you think about electric current. You may find it helpful to think about this while considering a set of instances. Some instances are printed as diagrams opposite. We used these, and others, to find out children's views of electric current. The individual sketches were made on cards and the child being interviewed was asked:

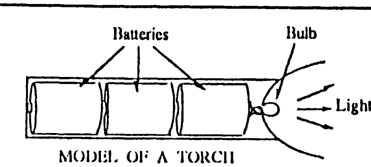
In your way of thinking about this, is there an electric current here?

The child's responses then provided the cue for further questions, for example,

Why do you think that? then *Can you tell me why you think that?*







The torch is switched on and the lamp is glowing.

Is there an electric current through the batteries ?

Which battery has the most current through it ?

By continuing this line of questioning, we obtained the views of a large number (several hundred) of students (aged from 8 to 18 years). The ideas put forward in Section 1.5 are from these interviews.

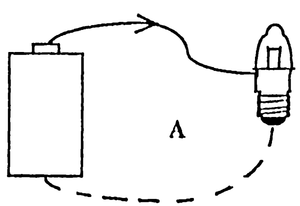
When you have recorded your view of electric current, think about ways of testing it. What evidence can you supply which supports and which does not support your view? It is this approach of seeking evidence to support, or negate, a view which makes this a scientific process. And it forms the underlying investigative approach in this teaching unit.

In clarifying your views on electric current you are trying to make sense of what you know and see. Your views may not be the same as the scientist's, but this does not matter. The important points are that you have a view, that you can articulate your view, and you are willing to test it. If you now look for evidence to support your view, and if you are prepared to modify your view in the light of new evidence, then you will have acted as a scientist would. In this teaching unit, we suggest that you and your students adopt a process of learning based upon these questions:-

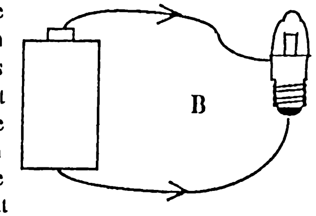
What is my view of electric current?
What does this view explain?
Is there evidence which does not fit my view?
Should I modify my view?
What is my view of electric current?
How useful is my new view?

1.5 CHILDREN'S VIEWS ON ELECTRICITY IN SIMPLE CIRCUITS

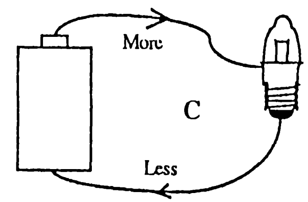
As a result of interviewing many children we have been able to classify their views about electricity in simple electric circuits into four main groups. These can be visualised by considering a simple system made of a cell or battery, a lamp, and two wires. Some youngsters have what we call a model A view. In this view, the electricity flows through one wire from the cell to the lamp, where it is "used up", and no current flows back to the cell. However, the second wire is required.



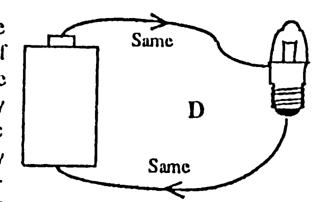
A second view, model B, is that the electricity flows through both wires from the cell to the lamp, where the currents "clash" to produce light and heat. Hence it is called a clashing currents model. Some students have a version of model B in which the two flows do not stop in the bulb but circulate and re-enter the battery at the other end



In a third view, the electricity circulates; it flows from the cell, through one wire to the lamp, where *some* of it is used up. The remaining unused electricity flows back from the lamp through the other wire to the cell.



In model D the electricity flows from the cell through one wire to the lamp, none of it is consumed and it all returns through the other wire back to the cell. This fourth way of thinking, model D, is the scientific explanation of electric current. In this view charges circulate, and are conserved. For most youngsters, this is a strange way of thinking about electric current, and it is this strangeness that causes learning difficulties. This teaching unit helps to overcome this difficulty.



1.6 A TEACHING PROCESS FOR THE CONCEPT ELECTRIC CURRENT

The scientist's idea of charges circulating and not being consumed is a fundamental concept which learners need if they are to make sense of much of their technological world, and if further learning of electrical phenomena is to be successful. Unfortunately, it is not a straightforward idea, and like most concepts, it is one which will need to be developed slowly, from many experiences. We suggest a structured teaching process, based upon a three-stage approach, to deal with this concept.

1.7 TEACHING PROCESS: PHASE ONE

The first phase of this process is one of *focussing* on the concept in a concrete way. This stage may be a lengthy one, because it is designed to bring students to the realisation that they do know many things about simple electric circuits, and it is necessary to nuture their confidence. As a result of uncovering this knowledge, your students will seek some sort of unifying idea, or generalisation, that will help them to explain what they know. And many will have already formed an explanation, but it is not likely to be the same as that used by scientists.

Much of the teaching activity in this first stage will be based on the teacher's skill in focussing children's thinking, through questions like these:

> *How do you think about the things you see happening in your circuit?*
> *Why does the battery go flat?*
> *How do you explain why the lamp glows?*

In this way, the teacher is preparing the learners for the second phase of this learning process. But before moving on, there are some further points about the first phase which the teacher needs to consider.

Some youngsters in your class will come from homes in which there are many electrical gadgets, toys such as electronic kits, and electrical games. One or both parents may have a technological occupation or hobby. Children from those backgrounds would be at an advantage over most other youngsters in learning about electricity. What can you do for the other children? One of the reasons for designing a lengthy first phase to this learning process is our recognition that some young people have not had many background experiences with electrical systems. We support this contention by recent research statements which indicate that girls do not get as much chance to fiddle about with mechanical and electrical equipment as boys do, and Polynesian children have little background experience with technological toys. In this unit, we try to build up their experiences.

In summary, phase one is a process of familiarisation and development of ideas, based on many experiences with simple equipment, enabling all learners to focus on the concept implicit in these experiences.

1.8 TEACHING PROCESS: PHASE TWO

The second part of this teaching process is dependent on the first phase, and it develops out of the need to explain what happens in simple circuits. We call this the *challenging* phase. Learners are encouraged to think about how they explain the events and effects in their simple electric circuits. We expect learners to formulate their views, and to modify them after they have *described, discussed* and *debated* their ways of thinking about electric current. For some learners this will be a stimulating time. This will come from the challenge of finding out just how useful their views, and those of their peers, really are. For other learners there will not be this personal intellectual satisfaction, but this is not a serious problem, as all learners will enjoy the opportunity to simulate the way scientists produce their theories. The task is to find a simple and brief statement to summarise what is known about electric current.

It is in this phase that learners will confront the present scientific view of this concept as one of the alternative ways of thinking about circuits.

This phase will enable teachers to identify learners who have scientific aptitude. These learners will be able to discriminate amongst different views, and they will be willing to modify their own views if a more powerful or more useful view is presented by another person.

Analogies are powerful aids in science learning, particularly when the science idea is strange and remote from learners' experience (as a model D view of electric current is for most youngsters). If learners can devise their own analogies to make sense of both their prior ideas and the new ideas, then the chances of a new view being adopted will be enhanced. Often the learner-devised analogies are not quite the same as the scientist's analogy, but their value is in being a transitional theory which may lead (later), by a process of analogy refinement, to more precise descriptions of electric current. This point is developed further in section 3 of this Teachers' Guide.

In summary, phase two is a process of clarifying of individual views followed by a challenge to each by other views held by class members. Learners are encouraged to discuss and debate their views, and to compare them with others, including the scientist's view. Evidence is sought to support all suggested views.

1.9 TEACHING PROCESS: PHASE THREE

The final phase in this teaching strategy provides another set of experiences, enabling learners to *apply* their view of electric current to new situations. The new views that learners adopt are of use if they enable them to make sense of electrical effects.

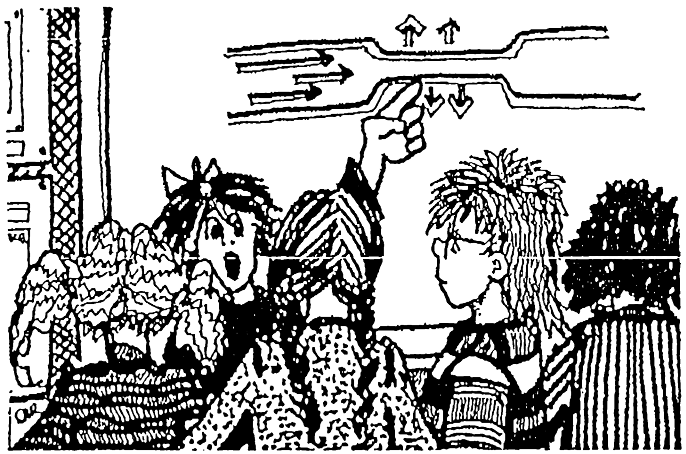
Teachers might feel that the hard work has been done in phase two, as all learners will now have seen the evidence for the scientist's model for electric current, but there are strong reasons for continuing with this topic. The main reason is to reinforce and consolidate a new view, so that learners can become *confident* in using this new view. We also want to convince learners of the usefulness of their new way of thinking about electric current, by allowing them to find out how it can help them to understand and explain other electrical systems. In some of our earlier research, we found that learners were more likely to accept a new view some weeks after it had been presented, rather than immediately after the teaching episodes. This process of delayed accommodation is not surprising. People generally are not very comfortable with a new idea at first, even though it can be accepted logically. We have to live with the idea for a time before we attain any degree of comfort in its use. The main point in phase three, then, is to provide the environment in which the new view of electric current can be nurtured until it is accepted by the learner, in the sense that Papert meant.

There is another reason for providing this third phase. From the point of view of the learners, the main contact they have with electrical phenomena is in the variety of technological appliances they meet in their everyday lives. We should enable students to make sense of the physics embedded in the electrical technology, and in this way, *to understand their environment.*
An important part of most science learning is the development of problem solving skills. If problems of a practical nature can be solved by youngsters, and if these problems invoke the new concept, then the concept's usefulness will be further strengthened.

In summary, the purpose of phase three is to consolidate a new view of electric current by reflecting on its value, especially when applied to realistic problems of everyday consequence.

1.10 CONCLUSION

Two major aspects of science have been exemplified in this teaching process. We have presented science as a process of *model making*, by refining people's models for electric current, and as a process of *problem solving*, by applying the scientific model to novel situations. The problems used in this strategy all have a technological flavour. This is deliberate. We live in an advanced technological society, surrounded by appliances and machines which contribute to our standard of living and quality of life. These materials constitute an appropriate environment in which this science concept can be nurtured. Thus technology will have a central place in science learning rather than being an add-on to abstract science.



ELECTRIC CURRENT

WORKBOOK

IN THE CLASSROOM - THE TEACHING PROGRAMME

2.0 EQUIPMENT NEEDED

Cell, 1.5V	Any general purpose battery is suitable.
Lamp, 1.5V or 1.3V	Ensure that throughout this unit all bulbs are identical.
Bulbholder	The lampholder made by Derry Recreation, Box 18772, Christchurch, is a robust holder suitable for use in this unit.
Switch	Two-way type.
Wire	Plastic coated hook-up wire, cut to 20 - 25cm. lengths, can be used.
Meters	Two ammeters, 0 - 500mA, are required.

Bell, electric motor, railway track and wagon.

OHP TRANSPARENCIES

A set of OHP transparancies and teaching notes is available for this unit.
(See Appendix 1)

INTRODUCTION

This workbook on electric circuits will help you to keep records of the things you do in this unit. While you are working through the material in this workbook, you can write down what you think is happening in the electric circuits you make.

The purpose of this unit is to explore the ways people think about 'electric current'. In the first part you will find out how to describe them, and you will become a Morse Code operator. In the second part of this unit, you and your classmates will consider your views on how you think about an electric current. Finally, you will meet a set of interesting practical problems and you can try to solve them.

Remember that the purpose of this unit is for you to form a view of what an electric current is.

SAFETY

Because you will be dealing with electrical equipment in this unit, you must decide on a set of safety guidelines to work with. Scientists take particular care to make sure that their equipment is safe to use, and that it will not harm other people.

Summarize your class safety rules.

....

....

....

....

....

....

FOCUS PHASE

2.1 QUESTIONS ABOUT ELECTRIC CURRENT

Students are invited to write down any questions they might have about any matter to do with electric current. Small pieces of card, or paper, about 10cm. square can be used. It is a good idea to display these questions on a pin-board in the classroom. Sometimes other members of the class will suggest answers. Other times, an experiment can be designed to check a question. Use of library resources can be encouraged. Perhaps an 'expert' could be invited to the class to provide answers, or to suggest solutions. The intention is to give status to the children's questions, to encourage curiosity, and to find out the matters which interest them.

Some examples: Why do batteries go flat?
Why don't birds get a shock from perching on a power line?
How are batteries made?
Why can some batteries be recharged?
What do AC and DC mean?

2.2 SAFETY

Electrical safety may seem to be out of place in this unit, where the equipment is very simple and of low power. However, the school's safety rules should be reinforced. Instruct students not to touch the mains supply with this equipment. Inform them that younger children might attempt some of these activities using the mains if they are not advised against this. Teach the 'backhand' way of testing all electrical equipment, and describe the physiological effect electricity has on muscles.

With younger children, we have used the Accident Compensation Corporation's safety posters as discussion starters. These posters are available from any office of the Accident Compensation Corporation.

MAKING THE LIGHT BULB GLOW

Obtain a torch cell (you would call this a battery, but it is better to call it a cell), a bulb holder and bulb, and two plastic coated wires.

Use this equipment to make the bulb glow.

Diagram of the equipment.

TESTING THE BULB AND THE CELL

Sometimes you find that the bulb will not glow, even though you have put the equipment together in just the same way as everybody else. What went wrong? Maybe the bulb has 'blown'. It is difficult to see the filament in a tiny bulb, so you have to find a better way of testing the bulb. How would you do this?

....

....

....

....

Perhaps the cell is 'flat'. How would you find out?

....

....

2.3 MAKING THE BULB GLOW

Students are issued with a bulb and bulb-holder, a cell (1.5V), and two lengths (25cm) of hook-up wire. Do not remove the plastic coating from ends of the wire. Some students assemble the equipment without removing any of the plastic coating from the wire. We did not arrange this to try to trick students. Rather, our purpose is to find out how many students have had experience with this type of equipment. This helps to decide how much familiarisation will be needed.

Students can be shown how to use a scissor-type wire stripper to remove the coating, exposing a 2cm length of wire, and/or a safe way of using a razor blade to cut a ring through the plastic coating, before the end section of the coating is removed.

2.4 TESTING THE BULB AND THE CELL

If the cells are not new, and if the bulbs have not been checked before use, then either or both might be defective. It is useful to show students how to test each, and to set up a test circuit on the teacher's desk so that students can bring a suspect bulb or cell to be tested. By replacing the cell in the test circuit with the suspect cell, the student can decide if the fault is with the cell; a similar process will identify a defective bulb.

At this point, some teachers introduce meters. A voltmeter can be used to test a suspect cell; an ammeter will provide information about the bulb.

Retain all defective bulbs. Students will enquire about the wire inside the bulb; it is easy to file away at the metal-threaded part to expose the conducting wires and the filament.

THE MORSE CODE

The electrical circuit which you have made can be used to send Morse signals.

Samuel Morse devised the Morse Code in 1838, about 40 years before Bell invented the telephone. This Code made it possible for people to communicate directly with one another over very long distances. In this Code the 26 letters of the alphabet are represented by 26 different sets of dots and dashes. When you send a message in Morse, make your dashes three times longer than your dots.

A .-	J .---	S ...
B -...	K -.-	T -
C -.-.	L .-..	U ..-
D -..	M --	V ...-
E .	N -.	W .--
F ..-.	O ---	X -..-
G --.	P .--.	Y -.--
H	Q --.-	Z --..
I ..	R .-.	

A Morse message which is quite famous is

.../___ /...

Do you know what this means? Write it below.

....

2.5 THE MORSE CODE

This activity is included here to provide students with several opportunities to assemble the simple circuit of 2.3. Students react favourably to its inclusion, particularly those who have not had much practical experience. The students who have had early experiences do not mind this either, particularly if they are challenged by the teacher to translate coded messages at speed. (If a person can handle 10 words a minute accurately, he or she will have achieved a high level of proficiency).

Morse messages are an essential part of war stories. It is claimed that an experienced Morse operator can detect a personal style in another's signalling. This has helped to recognise bogus messages sent by the enemy to trick the other side. Students know these and other things about Morse.

Messages in Morse, transmitted by the teacher, or written on the chalk-board, can be used to settle a class at the beginning of a teaching period.

You could send a message to your classmates. Write it in Morse in the space below.

Morse Message

MORSE MESSAGES

Turn this message into Morse

IS IT EASY TO LEARN A NEW LANGUAGE?

Can you translate this coded message?

. . / . . . // . . / _ // . / . _ / . . . / . . / . /. _ . // _ / _ _ _ //_ . _ . / _
_ _ / _ . . / . // _ _ _ / . _ . // _ / _ _ _ // _ . . / .
_ . _ . / _ _ _ / _ . . / . //

And this?

. _ _ / . . . . / _ _ _ / . . . / . // _ . . . / . . / . _ . / _ /
. . . . / _ . . / . _ / _ . _ _ // . . / . . . // . . / _ // _ /
_ _ _ / _ . . / . _ / _ . _ _ //

2.6 MORE MORSE MESSAGES

When students have completed the messages written in the workbook, the teacher decides how much more time should be spent on this activity. As well as sending additional messages, there are other things to do. Students can find out more about Samuel Morse, and his invention of telegraphy. It is worthwhile to consider the impact telegraphy would have had on people's lives 150 years ago.

Some students will think of ways of making the equipment more useful. Encourage this, as it is taken up in Section 2.9.

Who was Mr Morse?

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Can you find out more about Samuel Morse?

What do these words mean?

telegraph, telegram, telephone, teleprinter, television, telescope, teleconference, teletext.

. . . .

. . . .

. . . .

DRAWING THE EQUIPMENT

Use this page to draw a picture of the equipment you have used to send Morse signals. Try to make your drawings as accurate and exact as you can.

2.7 DRAWING THE EQUIPMENT

Keeping records of circuits made in class is an important aspect of this unit. Before introducing students to the code used by scientists and electrical engineers, the familiar circuit code, it is desirable to develop the matter of communication by asking students to draw the equipment they have used.

For some, this will provide an opportunity to display their skills at drawing. For more, however, this will prove to be a frustrating exercise, because they are not particularly skilled at drawing. The point of this is to bring students to the realisation that there has to be a better way. Better, that is, in terms of clarity, and economy of time and effort.

DESCRIBING THE EQUIPMENT

On this page write about the equipment you have used to send Morse signals. You could imagine that you are trying to tell another person, who has not seen this equipment, how he or she could make a Morse signal sender.

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2.8 DESCRIBING THE EQUIPMENT - USING WORDS

As in the previous section (2.7), the purpose is to bring about a realisation that it is not easy to communicate in writing with clarity and precision, either. Students will assure the teacher that 'they know what they mean', and the test of this claim is to ask another student to construct a circuit from a student's written record. Some students, nevertheless, can write clearly and concisely, and it would be fitting to recognise this skill.

EXTENDING THE SIGNALLING EQUIPMENT

Your task now is to think of different ways to extend the signalling equipment. You could include a switch, more lights, longer wires, and more cells. Write about what you try, and make a drawing, also note any interesting ideas other people suggest.

....

2.9 EXTENDING THE SIGNALLING EQUIPMENT

In a previous section (2.5), students constructed a Morse signaller, and used it. Some students will have extended the usefulness of this signaller. Let the students suggest, and try, various arrangements of equipment. They will need additional wires, more bulbs and holders, and extra cells.

Distribute a switch to each group. This will enable students to use it as a 'tapper', and to extend their knowledge of electrical equipment.

Some suggestions:

> Make a signaller which two people in different rooms can use. Each person would need a bulb and switch. It is interesting to watch the ways that students go about assembling the equipment.
>
> Enable students to show others the set-ups they have put together. Encourage students to share their ideas, and to talk about them.

Ask students to draw their set-ups.

USING A CODE TO DESCRIBE THE EQUIPMENT

On pages 6 and 7 you made a drawing and wrote a description of your equipment. Many people find that these methods are time - consuming, and it is hard to get them exactly correct. You may like to devise your own shorthand or maybe you know one already. One student has devised a shorthand which you may find helpful.
This person wrote:

1. BATTERY -- ⟶ BULB T,
   BULB S ⟶ BATTERY +.

Can you make a circuit from this instruction? You may have to ask your teacher to explain the code. Then try this:

2. BATTERY -- ⟶ BULB T,
   BULB S ⟶ SWITCH C,
   SWITCH R ⟶ BATTERY +.

You will have found that this is a very effective way of writing about an electric circuit, because it is simple, brief, and clear. Everybody can understand it.

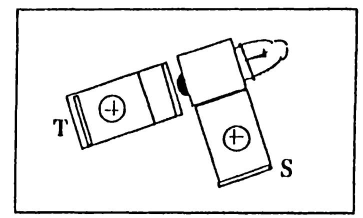
Now try these more complicated circuits. As you make each of these circuits, write down, in words, what happens to the bulb.

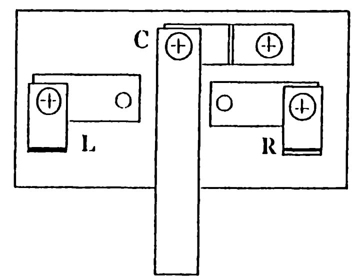
3. BATTERY -- ⟶ BULB 1 T,
   BULB 1 S ⟶ SWITCH C,
   SWITCH L ⟶ BULB 2 T,
   BULB 2 S ⟶ BATTERY +.

2.10 USING A CODE TO DESCRIBE THE EQUIPMENT

The issues raised in drawing and writing about simple circuits (sections 2.7 and 2.8) can be overcome by using symbols. Teachers will know the electrical symbols used to describe circuits. But before introducing the conventional system, try this constructor's code. In a trial classroom, one student produced his own effective way of keeping records as a result of experiencing the frustration associated with drawing and writing. Some of your students may make similar suggestions.

This student, an 11 year old, suggested that the contacts on each piece of equipment be given a symbol; e.g. on the bulbholder the symbol T identifies the contact to the *tip* of the bulb and the symbol S indicates the *side*, or screw contact of the bulb. For the cell, +ve and -ve have their usual meanings. For the switch; switch R identifies the right-hand contact, and switch L identifies the left-hand contact. Each arrow represents a piece of wire.





4. BATTERY -- ⟶ BULB 1 T,

BULB 1 S ⟶ BULB 2 T,

BULB 2 S ⟶ SWITCH C,

SWITCH R ⟶ BATTERY +.

....

....

5. BATTERY 1 -- ⟶ BATTERY 2

BATTERY 2 + ⟶ BULB T,

BULB S ⟶ BATTERY 1 +.

....

....

6. BATTERY 1 + ⟶ BATTERY 2 --,

BATTERY 2 + ⟶ BULB T,

BULB S ⟶ BATTERY 1 --.

....

....

7. BATTERY 1 + ⟶ BATTERY 2 --,

BATTERY 2 + ⟶ BULB 1 T,

BULB 1 S ⟶ BULB 2 T,

BULB 2 S ⟶ BATTERY 1 --.

....

....

This simple code provides an opportunity to introduce more circuits, thus providing experience in handling the equipment, and extending the students' knowledge.

Circuit 1 summarises the circuit met in the first activity (2.3).

Circuit 2 incorporates a switch into circuit 1.

Circuit 3 allows for two bulbs to be built into a circuit. Students will notice that each bulb glows, but dimly. They should record this observation, and the teacher will ask
What do you think is happening in this circuit?, and
Why are the bulbs so dim?
If one of the bulbs is loosened so that its T contact is not touching the plate, then both bulbs go out. Ask
Why does this happen?

Circuit 4 is much the same as 3. Here the components are linked in a different order. Does this make any difference to the brightness of each bulb?

Circuit 5 introduces a second cell, linked -ve to -ve. If the instructions are followed, then the bulb will not glow. Ask
Why doesn't the bulb glow?

Circuit 6 corrects circuit 5, and the bulb glows more brightly than before. Enquire, to find out what your students think about this.

Circuit 7 extends circuit 6 by introducing a second bulb. Here, each bulb should display the same brightness as the bulb in circuit 1.

Circuit 8 has 2 cells and 3 bulbs (in a line - we say "in series").

Circuit 9 illustrates another practical situation, whereby one bulb is controlled by two switches, as in a hallway or stairwell.

8. BATTERY 1 + ⟶ BATTERY 2 --,

BATTERY 2 + ⟶ BULB 1 T,

BULB 1 S ⟶ BULB 2 T,

BULB 2 S ⟶ BULB 3 T,

BULB 3 S ⟶ BATTERY 1 --.

This is a particularly interesting circuit. If you loosen any one of the bulbs so that its T contact is broken, what happens? Try it.

....

This is known as the "Christmas Tree Lights Problem". Does it happen with your Christmas tree lights too; when one bulb is defective, none of the bulbs can glow? Surely there is a better way of arranging the wires so that if one light is broken, the remainder will still glow? We will return to this problem later.

9. BATTERY + ⟶ BULB T,

BULB S ⟶ SWITCH 1 C,

SWITCH 1 L ⟶ SWITCH 2 R,

SWITCH 1 R ⟶ SWITCH 2 L,

SWITCH 2 C ⟶ BATTERY --.

This is an interesting circuit, too. Can you find a circuit in your home which is like this? Could you find a use for this circuit?

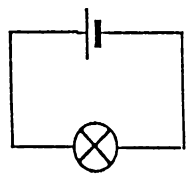
....

10. Do you know of any other interesting circuits which you could write down in constructor's code?

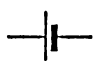
THE ELECTRICIAN'S CODE

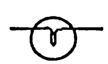
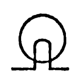
The code that you have been using in the 9 circuits on the previous pages is a useful code, because it helps you to build circuits. It is called a constructor's code. There is another code for describing circuits.
It goes like this:

Circuit (1)



Electricians, engineers and scientists use this code. Its symbols are:

cell or battery  three cells 

lamp  or  or 

switch  or 

On the rest of page 12, and page 13, draw the electrician's codes for the circuits numbered (2) to (9) on the previous pages. When you have finished these, check your drawings with those of others in your class, and with your teacher.

Which of the four methods of recording - drawing, writing, constructor's code, and electrician's code, do you prefer? Why?

2.11 THE ELECTRICIAN'S CODE

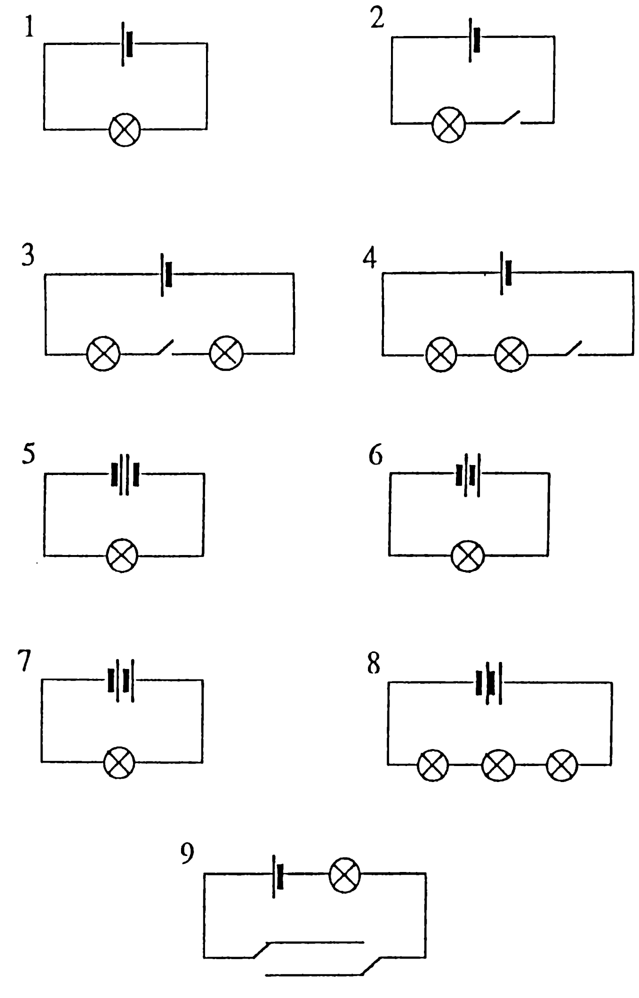
If the students can use the constructor's code outlined in section 2.10, then the transition to the electrician's code will be achieved almost nonchalantly.

The teacher will need to explain why another code is used. We think that the constructor's code is very useful in helping to put circuits together. The electrician's code is more useful when it is necessary to form a picture of how the equipment is laid out.

Some students can translate the constructor's code into the electrician's code without building the circuit, and the teacher might find this acceptable. However, for many students it will be better if the constructor's code is used to make the circuit, and then this made-up circuit should be translated into the electrician's code.

THE ELECTRICIAN'S CODE, continued

Circuits 1 - 9 on pages 17 -19 in electrician's code.



WHAT YOU KNOW ABOUT ELECTRIC CURRENT

You will have often heard people use the words 'electric current'. You will have also thought about what must be happening in the wires, the battery, and the bulb when a light bulb is glowing.

How do you think about the flow of electricity, the electric current, in a simple circuit?

Write down what you know already and the questions you have about electric current. To ask a good question can be very useful in helping to learn about something.

....

....

....

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....

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Workbook

2.12 SUMMARY - "WHAT I KNOW ABOUT ELECTRIC CURRENT AND CIRCUITS."

We have recorded a summary prepared by a class taking part in one of the early trials of this unit. These students noted these points.

Testing electrical equipment; safety.

1. Treat electrical equipment as if it is alive.
2. Touch electrical equipment with the back of your hand first.
3. If a person is getting a shock, do not touch him or her. Remove the electrical source first.
4. Cardiovascular resuscitation may get a shock-victim's heart beating again.

Electric fences - (many of the students came from farms)

1. You can get a shock from an electric fence.
2. The shock from an electric fence is worse in bare feet.
3. Insulators, like plastic, can help you to avoid getting a shock.
4. Birds do not get shocks from electric fences.

Circuits

1. A circuit is needed to make a bulb glow.
2. Connect a +ve on one battery to the -ve on another to make a bulb glow more brightly.
3. If two bulbs are linked to one battery,
   they will both glow dimly if they are in one line, or
   they will both glow brightly if they are linked separately to the battery.

UNDERSTANDING ELECTRIC CURRENT

The next section of this unit is where you can think about your ideas and those of others.

There are a number of different ways that people think about electric current in a simple circuit (we call them different models of electric current). It is helpful to sort out your own ideas by thinking about the different models. You also need to think about which one you prefer, and why.

You will then need to think how you can get evidence to show which model fits the facts.

If the evidence supports a model which is not the model you chose, then you might want to rethink your ideas.

On the next page are drawn four models of electric current that other pupils have proposed. What do you think about these models? Are they good ones? Which one(s) agree with what you know already.

4. The usual way to link Christmas tree lights is not very good because if one light blows, they all go out. A better way is to wire each light separately.

5. Two two-way switches can control one light, as in a hallway.

6. We know about two types of switches.

7. I know that the lights in my house are not linked in a line like the Christmas tree lights.

Language

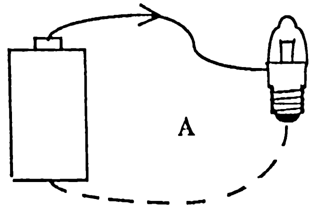
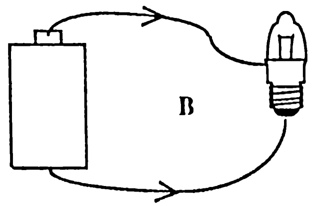
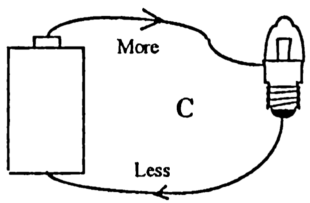
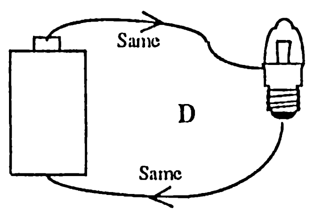
1. Learning the Morse Code is a slow process.

2. Coding into Morse is easier than de-coding Morse into English.

3. A constructor's code can help to make circuits quickly.

4. The electrician's code helps to get a picture of how a circuit is made, and how the parts are linked together.

5. Symbols save a lot of time in keeping notes and records, particularly if everybody uses the same set of symbols.

Four different models	My ideas
	
	
	
	

CHALLENGE PHASE

2.13 CONSIDERING VIEWS ABOUT ELECTRIC CURRENT

This section contains a critical lesson in which students describe, discuss and debate their views of electric current. It can be taught in this sequence:

1. The teacher describes each of the four models for electric current, without any reference to the 'correct' one.
2. Each student decides which model best fits her or his way of thinking about electric current.
3. Each student writes in the box adjacent to each model whether he or she sees any merit in each of the models.
4. The teacher asks the class to indicate, by a show of hands, who prefers which model. These indications are recorded for each model (see page 42).
5. Students of differing views are paired up. For example, a student holding the model B view is paired with a student who holds model C. These pairs of students discuss their views, attempting to convince the others of the validity of the view held. Equipment can be used.
6. As a result of this discussion, each student records whether her or his view has changed (using the table in the workbook). Record the class responses on page 42.
7. A class discussion is used to find if there is a common view. Sometimes there is (and often model C is the acceptable view). Other times, there will be a variety of views.
8. Evidence is sought for each of the views remaining. Students will propose that a successful model will enable them to explain the cell becoming flat, and the bulb producing light and heat.
9. The teacher describes how an ammeter can provide information about the current in each wire, by comparing the ammeter's information with that provided by the black rubber strip road engineers use to count cars when it is laid across one lane of a road. If separate black rubber strips are laid across single lanes they count the number, and the direction of flow, of the cars.

How others think	After the teaching	At the end of the unit

10. After the meters have been introduced, using page 18 of the Workbook (Teaching Notes 26), the teacher will indicate the meter reading in one of the wires. In our case, this value was 0.21 amp. Students record their predictions for the meter reading as each of the models is considered in turn.

11. Next, the crucial test. The teacher installs a milliammeter on each side of the cell-bulb circuit. It is vital that this be tried out beforehand, as it is necessary to get the circuit and meters correctly linked. Remember to link the +ve terminal of the cell to the red terminal of the ammeter.

12. The ammeters show the same reading on each side of the circuit. To scientists this means that current is conserved. For many students this is a strange, unexpected, and inexplicable result. Others will conclude that model B has been supported.

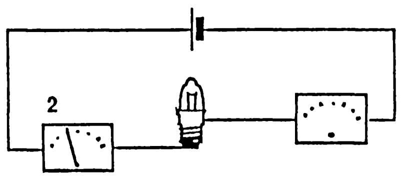
13. Each student completes the second part of page 18 of the Workbook, and writes a comment in the third column of the table on pages 16 and 17. Record the class responses on page 42.

14. Students will need time to check the circuit with the ammeters installed. If a class set of ammeters is available, repeat the experiment.

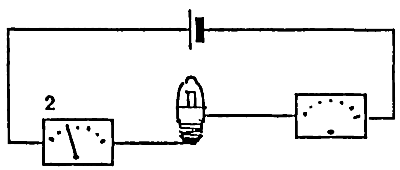
WHAT DO THE METERS INDICATE ?

Write down what you think the meter on the right in each of the diagrams shows if the meter on the left shows "2", for each of the four ways of thinking about electric current.

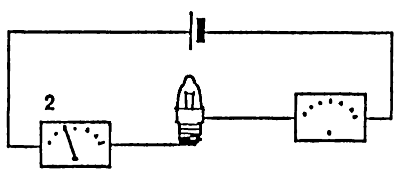
A



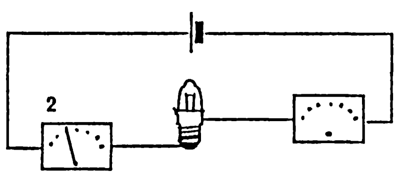
B



C



D



Which one agrees with what you saw on the meters ?

Workbook

2.14 WHAT DO THE METERS INDICATE?

In our trials, the introduction of meters and their use to discriminate amongst the four models caused some trouble. This was not unexpected, but for some students there was a big problem and we are not sure yet what should be done. The models cannot be sorted out without using suitable ammeters. But some students are not able to accept the logical impact of the meter readings. It seems that the logic involved is too demanding.

WAYS OF THINKING ABOUT ELECTRIC CURRENT

Electric current seems very mysterious when you first learn about it. We cannot see it, taste it, or normally feel it. However we talk about it because it is something that we can measure with a meter, called an ammeter, and we know quite a lot about what it can do.
It took a hundred years for scientists and inventors using a combination of guesswork and experiment to get an idea of what is happening in a battery - bulb circuit. It is not surprising that we find it hard to understand.
Through our experimenting we have found that the ammeters tell us that the electric current circulates around the circuit and is the same at every point in the circuit. Scientists even find the current is the same in the battery!
To make sense of this, we have to think of electric current as carrying the energy to the bulb to make it glow, and not as the energy itself.

One student who thought about this, liked to imagine the electric current as if it were a line of trucks or railway wagons.
The trucks travel around the circuit picking up coal or something similar from the battery and delivering it to the lamp(s). The trucks are really the electric current and the coal is the electric energy that makes the lamp glow. The trucks go around and around until the battery goes "flat".
This student found that thinking of the electric current in this way helped him to explain how electric circuits worked.

What do you think of his idea ?

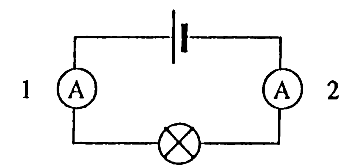
Can you invent your own way of thinking about the current ? Discuss your ideas with your teacher and with your classmates.

2.15 AIDS TO UNDERSTANDING THE SCIENTIST'S VIEW OF ELECTRIC CURRENT

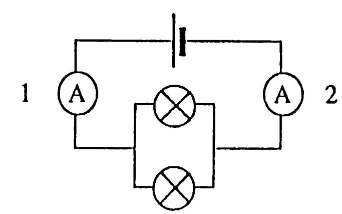
This treatment of the concept electric current has been designed to separate the notion of current from that of energy.

For many learners the evidence provided by the ammeters, that current is conserved, is hard to accept as, for them, this means the battery would never go flat. Encourage students to invent their own analogies, such as the one described opposite, to explain both the meter reading being the same and the battery going flat.

A simulation can be used to describe one way of thinking about electric current and to provoke further thinking and discussion. Obtain 50 cardboard squares, about 5cm x 5cm. On each write '1U' (1 unit). One student acts as the cell, or battery, another is the bulb, others (10) act as electrons. Sketch this circuit on the floor, playgrounds, or tennis court:



The battery student gives each electron student a 1U card, and the electron students walk around the circuit to the bulb, where the card is handed to the bulb. The electron students then walk back to the battery, and take another 1U card. Observers at locations 1 and 2 observe the flow rate and direction. The process continues until the cell has no more 1U cards left, i.e. the cell is flat. Observers at 1 and 2 will note that the flow rate is the same.
Now extend this simulation to this circuit:



Encourage students to talk about these simulations.

SIMULATION

Your teacher will show you a simulation in which moving people play the part of electric current, and tickets take the part of energy. Let's start with the switch open (off). People are spread out around the circuit but they are not moving; there is no flow or current. When the switch is closed (on) people start circulating, forming a current. Each person represents what is called a freely moving electric charge. In a metal they are electrons.

As you pass through the battery you gain energy represented by a ticket. As you pass through the bulb you lose the energy. However the electric charge (that's you!) which carries the energy is not used up (just as well for you). If everybody remains evenly spread out around the circuit, the number of people going past any point in the circuit each second remains the same. The flow is the same at all points. Electric current is the same at all points in this circuit.

FURTHER IDEAS

If you are keen to follow up any of the ideas in this section, your teacher has some notes about scientist's ideas for you to read.

If your school has a BBC or Apple IIe microcomputer then you can obtain a disk, ELECTRIC CURRENT SIMULATION, which will allow you to further check your ideas.

SOLVING TECHNOLOGICAL PROBLEMS

The following problems are designed to help you learn more about electrical circuits. You will see how your view of current can help to solve practical problems.

Some problems are easy and some more difficult. They require you to THINK!

VIDEO

The video cassette TEACHING ELECTRIC CURRENT includes film of students performing this simulation.

2.16 APPLICATION PHASE

This, and the following problems, challenge students to find answers to these problems about practical situations. There are no 'right' answers, but some solutions will be more effective than others. We found that most students could arrive at a 'parallel' arrangement in a short time, but occasionally a novel solution is proposed. Look for these.

Problem 1 The Christmas Tree Lights Problem.

Why is it when one light goes out on a set of Christmas tree lights, all of the light bulbs go out?

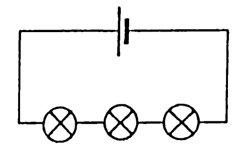
Can you connect up a set of three bulbs to show this happening? Loosen one of the bulbs until it is no longer in contact with its T plate. What happens?

This is a nuisance, isn't it? Perhaps there is a different way to connect three bulbs so that if one bulb is "out", the other two will keep going. Try to make this happen. Use this page to write down your answer to this problem. Write down the things that you observe, and also write down any less successful combinations of lights you tried. Use this page and the next for your drawings and diagrams.

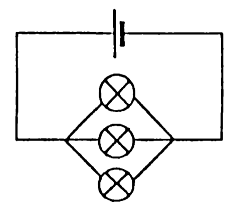
When you have finished this problem, talk to the teacher about your solution. Find out about other student's answers. After this, try Problem 2.

THE CHRISTMAS TREE LIGHTS PROBLEM

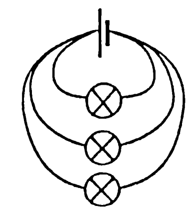
1. If one bulb is removed, the circuit is broken and the lights go out.



2. A suitable answer is



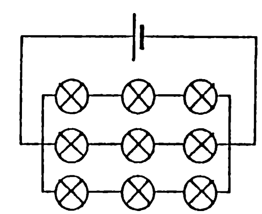
and this could be drawn like this ⟶



In this circuit the lights are brighter than in (1) above. Why is this?

3. In the U.S.A. Christmas tree lights are linked like this.

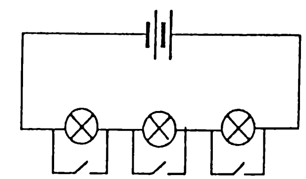
If one bulb goes out six will stay on.



Drawings for Problem 1

One student proposed this solution:

If switch 1 is closed, and bulbs 2 and 3 glow, then bulb 1 is the defective one. If switch 2 is closed, and bulbs 1 and 3 glow, then bulb 2 is the defective one.



Problem 2 Keeping the Kaimai Tunnel Clear.

How much did it cost to build the Kaimai Tunnel? No doubt you think it cost many millions of dollars. And, it did. It is vitally important that there are no accidents inside this tunnel, and you might be able to suggest a way that the Railways Corporation could use to find out if a train, or a carriage, or a truck was inside the tunnel. (The tunnel is too long to see from one end to the other). You might be able to think of a way, using lights, which would tell the driver of a train approaching the tunnel that there is already a train inside the tunnel.

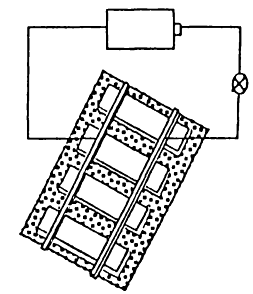
Write or draw your answer on this page. (You can use model railway tracks to help you solve this problem).

Talk to your teacher about your answer.

2.17 KEEPING THE KAIMAI TUNNEL CLEAR

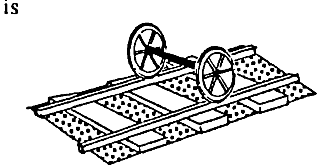
This problem is simple enough, and is more realistic if a strip of model-railway track and a wagon are provided. The circuit shown below is satisfactory if the wagon is on the rails, but it is not useful if there has been a derailment.

Set up this circuit:



Now what would make the light glow?

If a metal axle is across the tracks then the circuit is complete.



The problem can be developed further. One group of students used 2 bulbs, one at each end of the tunnel, to show if a wagon is on the rails in the tunnel. Then these students considered the problem of a bulb failure, and they placed 2 bulbs, in parallel, at each end of the tunnel. If one bulb failed, some very interesting things happen in this circuit. Other students considered that an electrical conduction method was not really suitable - a train may not even be in the tunnel, yet it can be detected. While this point was dealt with by isolating the rails in the tunnel from the tracks leading in and out, students were concerned about a derailment. These youngsters suggested placing video-cameras at each tunnel mouth, with the cameras reading a code on the side of each wagon. A computer would process the data.

Problem 3A Traffic Lights.

Engineers who look after the roads in a town sometimes use traffic lights to control the flow of cars and trucks (and bikes) at busy intersections.

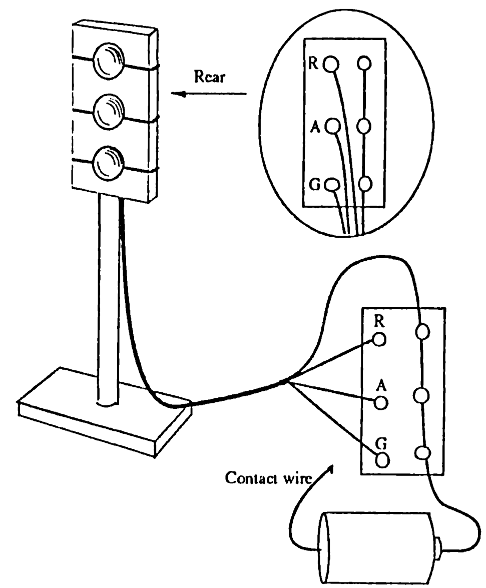
You could try to make a set of traffic lights, with three of the light bulbs in the electrics kit. There are lots of ways of doing this, and your teacher is interested in how you would go about it. Make a set of lights, draw a diagram and write down how you made it.

2.18 PROBLEM 3A

TRAFFIC LIGHTS

These two problems about traffic lights generate considerable interest, and they can be developed to provide a worthwhile challenge for students interested in making a display for a science fair.

Obtaining a first solution is straight forward if learners manually change the lights. But, the problem becomes more interesting when learners are challenged to use switches. First a mechanical switching system can be 'invented', then electromechanical and electronic control systems can be introduced. A robotic Lego set can be used (Lego kit 1092, plan B).



A manual traffic lights set.

Problem 3B Traffic Lights.

Now that you have wired up a set of three lights to act like a set of traffic lights, you might want to extend your set of lights by adding three more lights to control the traffic on the road intersecting with the road controlled by your first set of lights.

When your light shows "green", the lights on the intersecting road must be "red", this is a hint on how to wire up the lights.

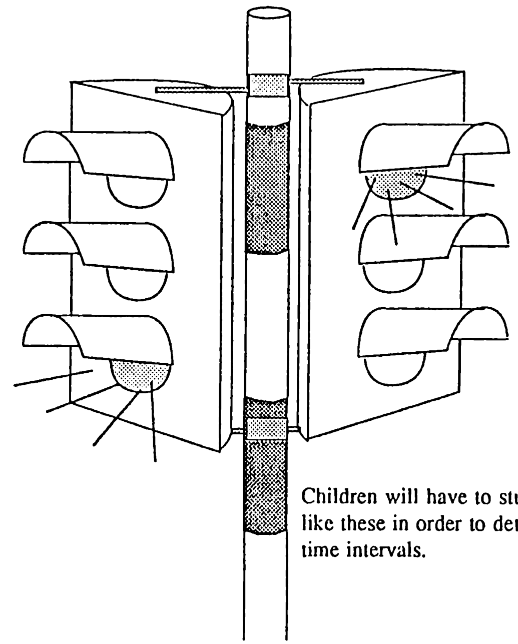
Draw a diagram and write about your answer. Talk to your teacher when you have solved this problem.

2.19 PROBLEM 3B

TRAFFIC LIGHTS

This second traffic lights problem is an extension of problem 3A, and it is suitable for those youngsters who show an interest in the design of traffic lights.

It can be tackled in two ways. In one, the students simply make two sets of lights behave as if they were traffic lights. In the other, students attempt to build working models of traffic lights. While this latter approach will consume much time, for a small group of students this will be the way they would want to approach these traffic lights problems. The teacher needs to decide if these students should continue with the remaining problems before attempting a detailed development of simulated traffic lights.



Children will have to study a set of traffic lights like these in order to determine the sequence and time intervals.

Problem 4 Doctor's Call Code.

In some hospitals, there were panels of lights in the corridors. Each doctor in the hospital has his or her own pattern or code that lights up when the telephone operator wants the doctor to phone in.

Can you make a panel of three lights so that seven different doctors each has a different code?

How many lights would you need to provide each member of your class with a personal number?

This number system is called a binary code, because each of the lights can be in either the "on" or the "off" position. Do you know of other devices which use binary numbers?

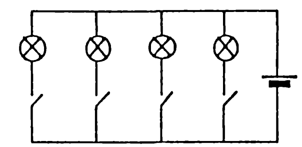
Describe your set - up here, then tell your teacher about it.

2.20 PROBLEM 4

DOCTOR'S CALL CODE

With binary systems being part of students' mathematical education, this problem can give physical meaning to that knowledge.

No doubt hospitals have a more elegant method of communication these days!



The Binary Code

If two lights:

○ ●	1 off, 1 on
● ●	2 on
● ○	1 on, 1 off
○ ○	both off

If three lights:

● ● ●	3 on
● ● ○	2 on
○ ● ●	2 on
● ○ ●	2 on
● ○ ○	1 on
○ ● ○	1 on
○ ○ ●	1 on
○ ○ ○	3 off

If four lights:

● ● ● ●	4 on
● ● ● ○	3 on
○ ● ● ●	3 on
● ○ ● ●	3 on
● ● ○ ●	3 on
● ● ○ ○	2 on
○ ○ ● ●	2 on
○ ● ● ○	2 on
● ○ ○ ●	2 on
● ○ ● ○	2 on
○ ● ○ ●	2 on
● ○ ○ ○	1 on
○ ● ○ ○	1 on
○ ○ ● ○	1 on
○ ○ ○ ●	1 on
○ ○ ○ ○	4 off

The general formula for the number of possible call codes is $2^n - 1$, where n is the number of lights.

Problem 5 Car Heater Switches.

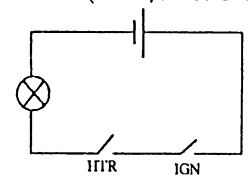
In many cars, the heater can be turned on when the ignition key switch is in the 'on' position; there are two switches. Can you imitate this type of circuit, using the light bulb to represent the heater?

Write your answer here, then talk to your teacher about it.

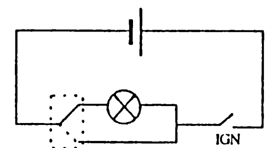
2.21 PROBLEM 5

CAR HEATER SWITCHES

This problem starts off as a straightforward one, and for most students the first solution (below, the bulb represents the heater) is all that needs to be done.

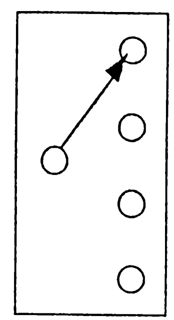


Some students will see that this solution has a flaw. It is not possible to turn on the ignition unless the heater is turned on.



This may be an improvement.

But, some students will not be satisfied with this answer, because they know that the heater has several different settings, varying from OFF, through WARM to HOT, then VERY HOT. A four-position switch could be made, and there are other ways of dealing with this problem.



Off	
Warm	1 heater element on, fan on slow
Hot	2 heater elements on, fan on slow
Very Hot	2 heater elements on, fan on fast

This switch can be built from 5 drawing pins pressed into a small piece of Pinex. A paper-clip can be the conductor from the central terminal to the other 4 terminals.

Problem 6 A Lighting System for a Mine or Tunnel.

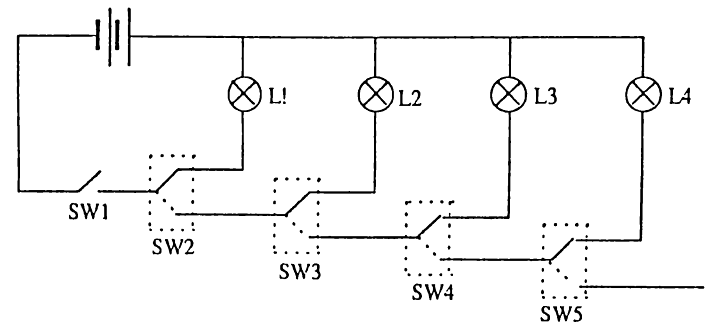
Can you build a set of four lights so that when you go into a mine, you turn the first light on , then when you have walked about 30 metres, say, you turn off the first light and at the same time, turn on the second light? In this way you put on the light in the part of the mine you are in. Then on going further into the mine, you turn off the second light and at the same time turn on the third light.

This seems to be a complicated problem, but it can be solved if you think about it. Try to make this arrangement of lights and switches, then record your answer. Other people will be interested in your answer.

2.22 PROBLEM 6

A LIGHTING SYSTEM FOR A MINE OR A TUNNEL

This is a nasty problem (we think), but to some students it presents a challenge which they accept and enjoy. There may be other solutions as well as that shown here; we found the solution presented below difficult enough to formulate.



SW1 is a simple switch, which turn L1 on

SW2 is a two-position switch which turns L1 off and L2 on

SW3 is a two-position switch which turns L2 off and L3 on

The miner has to turn the lights on as he or she comes out of the mine, because each switch is needed as part of the circuit for the light near it.

What happens if there is an accident down the mine, by Light 4? Can rescuers use the lights?

Problem 7 Car Indicator Lights.

When a car driver flicks a switch to show that he or she intends to turn his or her car to the left, the indicator lights known as LEFT FRONT and LEFT REAR flash on and off. And if he or she had decided to turn to the right, by flicking the switch in the opposite direction, the RIGHT FRONT and RIGHT REAR indicator lights would flash on and off.

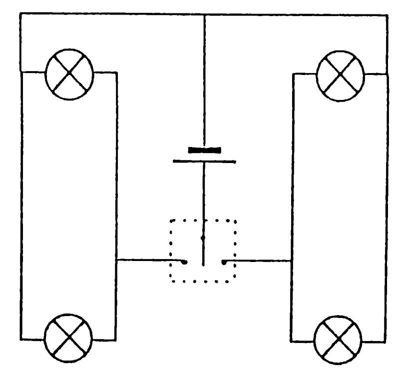
Can you imitate this using one switch and four lights? You will not be able to make the lights flash on and off yet, but you might have some ideas on how this could be done.

Write down your system, then tell your teacher about it.

2.23 PROBLEM 7

CAR INDICATOR LIGHTS

This interesting problem can be further developed if students are challenged to find a way of interrupting the circuit to provide a flashing effect.



Problem 8A A Visitor at the Door.

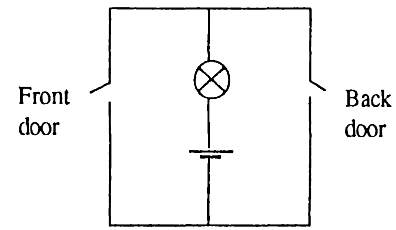
Some homes have a set of door chimes in the hall, with push - button switches at the front and back doors. If you can borrow a bell, you might be able to connect two switches (representing the front door and rear push - button switches) to the bell.

How would you do this? Make it work, write down how you did this, and compare your circuit with other people's circuits.

2.24 PROBLEM 8A

A VISITOR AT THE DOOR

This pair of problems will be enhanced if a suitable bell is available. To us, the first problem is straightforward, and the second allows for considerable inventiveness.



Problem 8B A Visitor at the Door - Helping a Deaf Person.

In Problem 8A, you built a bell system for the front and back doors of a house. Now, how could you modify this set up for the home of a deaf person? You could use a light in place of the bell.

Let's make the problem more interesting.

If only one person in the house is deaf, then a system which turns on both the bell and the light would be desirable. Can you do this?

Can you modify the system using a light so that the deaf person in the house can tell, by looking at the bulb, that the visitor is at the front door or the back door?

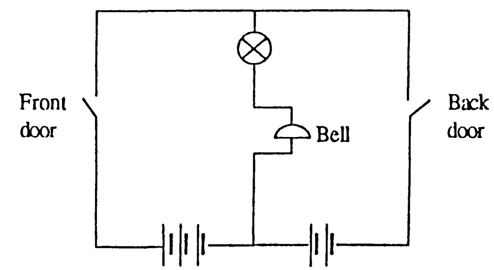
Record how you did each of these, then tell your teacher about them.

2.25 PROBLEM 8B

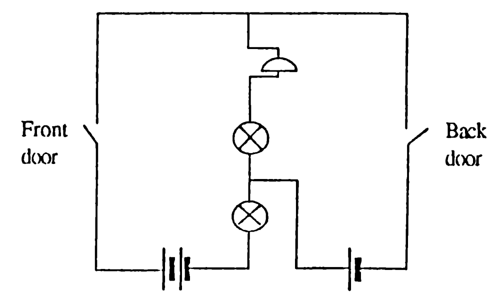
A VISITOR AT THE DOOR - HELPING A DEAF PERSON

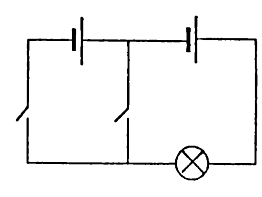
Students accept the degree of incapacity a deaf, or blind person has to cope with, and they will be keen to help by solving these problems. There should be a variety of solutions. Encourage students to describe their suggestions to the class.

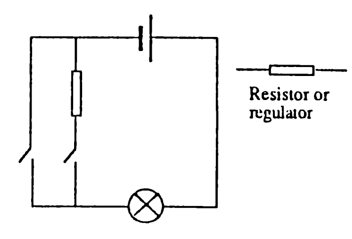
Does this work?



Or this?







Problem 9A Changing the Speed of an Electric Motor.

Obtain a small electric motor from your teacher. Using a 1.5 volt cell, make it operate.

Can you now reverse this, so that the shaft rotates in the opposite direction? (Use the idea of clockwise, and anti - clockwise - when you are looking at the motor from the shaft end to describe the direction of turning).

The method used

Make the motor turn faster than it did with a 1.5 volt cell.

Make the motor turn more slowly than it did with a single 1.5 volt cell. Your model for electric current will help you to make predictions.

2.26 PROBLEM 9A

CHANGING THE SPEED OF AN ELECTRIC MOTOR

This problem has been included to round off the section on problem solving with circuits. This problem, to change the speed of an electric motor, has direct links to learners' concepts of electric current. If the charge flow is increased, then the motor will spin faster; if the charge flow is decreased, then the motor will spin more slowly. Most students should, now, be able to use their ideas of charge flow in solving problem 9A. However, the technical problem of bringing about these effects will require some thought.

One solution requires a 3v battery, and one small motor. If the charge flow can be reduced, the motor will turn more slowly. Students may suggest the incorporation of a bulb in the circuit. This seems to be a good idea. Will two bulbs cause the motor to spin more slowly still? The stainless steel spring from a ballpoint pen has been used as a resistor.

Problem 9B Electric Motor.

The methods of changing the direction of turning for electric motors are useful for people who design lifts and cranes. The problem now is to find a way to do this with a switch. Can you think of a way that a switch could be used to change the direction, from clockwise to anti - clockwise?

Questions to think about.

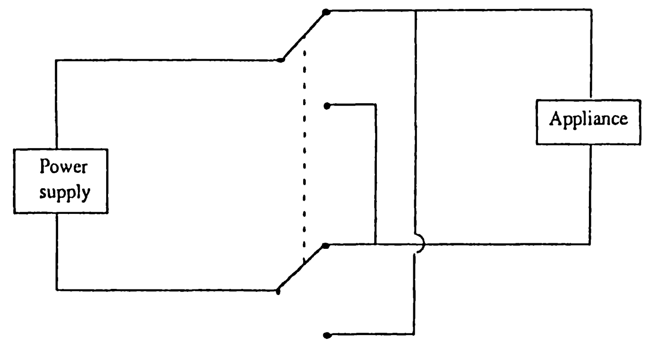
How fast is the motor turning when it is linked up to two 1.5 volt cells? The makers of the Johnson 150 motor claim that, when there is no load on the motor, its speed is 4500 r.p.m. (revolutions per minute). How would you check this measurement?

2.27 PROBLEM 9B

ELECTRIC MOTOR-EXTENSION

This problem is very much an extension activity for more thoughtful students.

Changing the direction of rotation will require a change in the direction of current flow. A reversing switch is needed. Two switches can be converted, like this



The second part of this problem is an opportunity to demonstrating stroboscope techniques. Borrow an electronic stroboscope from the Physics Laboratory. Stick a small strip of sticky tape to the shaft of the motor, then set it spinning. The stroboscope will "freeze" the motion of the tape strip when it is flashing at the same rate as the motor is rotating. Just before, and just after, the matching of the two rates, the well-known stage-coach wheel effect will be seen.

OTHER PROBLEMS

You and your students will suggest other problems like this. For example, the circuit for the light in the refrigerator, and burglar alarms, are interesting circuits. We think that circuits like this open up thinking about switches, from simple manual switches, through electromagnetic switches (e.g. relays) to electronic switches (and then logic systems).

SUMMARY AND EVALUATION

Now that you have completed this unit on electric current, it would be worthwhile to turn back to the table on pages 16 and 17, and to complete the final column. Make sure you write down your own view, the view you now have, of electric current.

The teachers who prepared this unit on electric current are interested in your opinion on the things you have studied in this unit. Use this page to write about the things that you most enjoyed, and the things that you least enjoyed. If you would like to make some other comments, please write them here, too.

2.28 SUMMARY AND EVALUATION

At the end of the unit, the first task is for the students to return to pages 16 and 17 of the Workbook and complete the fourth column of that table. The teacher can then record the class views in the table below.

Class summary: students' responses to the models.

Model	At the start of phase two	After class discussion	After the meters experiment	At the end of the unit
A				
B				
C				
D				

ANALOGIES, MODELS AND SIMULATIONS

3.1 INTRODUCTION

The analogies which *our* students have devised to make sense of the two observations,

the battery goes flat eventually and
the current is conserved,

have generally been of a two-particle moving nature

e.g. coal in trucks
fuel and transporter (carrier).

gets used up (consumed) — don't get used up (conserved)

This consumption-carrier model explains

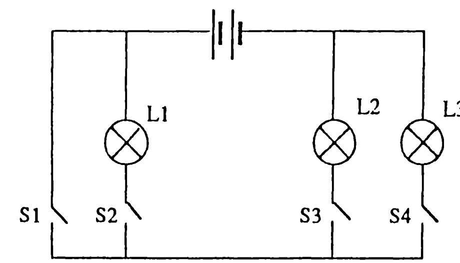
the light glowing,
the current being conserved,
the battery going flat,
two lights in parallel being equally bright,

and for some students this is good enough. For others, there are problems with this model. For example, when you consider two lights in series, how does the analogy deal with the observation that the two lights are equally bright?

You and your students may want to go further. If so, you can

1. modify the existing analogy,
2. devise another analogy,
3. investigate the computer simulation, and
4. investigate the water model.

Our computer simulation and water model are based on this circuit.



3.2 COMPUTER SIMULATION

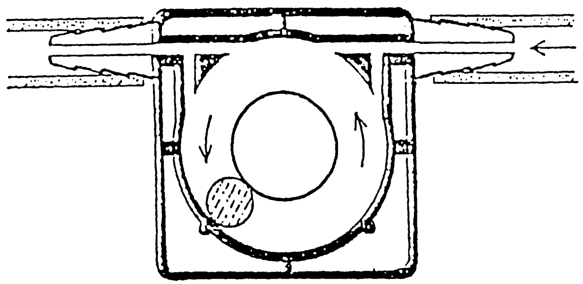
The simulation can be used in this way:

1. Explore different switch settings trying to predict what will happen before trying a new setting.
2. Set up the circuit using the electrical gear and compare this with the simulation.
3. Think about the particles as squeezing through the lights and compare with the consumption-carrier model.
4. Answer these questions:
   Which switch settings would flatten the battery quickest?
   Which switch settings would flatten the battery slowest?
   Why?

3.3 WATER MODEL.

We have made a water model using a bilge pump and flow-watchers. The flow-watchers are the most important part of the model and represent lamps as well as ammeters. The number of revolutions made by the flow-watcher bead, in say ten seconds, can be counted and this number is a measure of the water flow.

Flow-watcher



As with the computer simulation, the water model can be used :

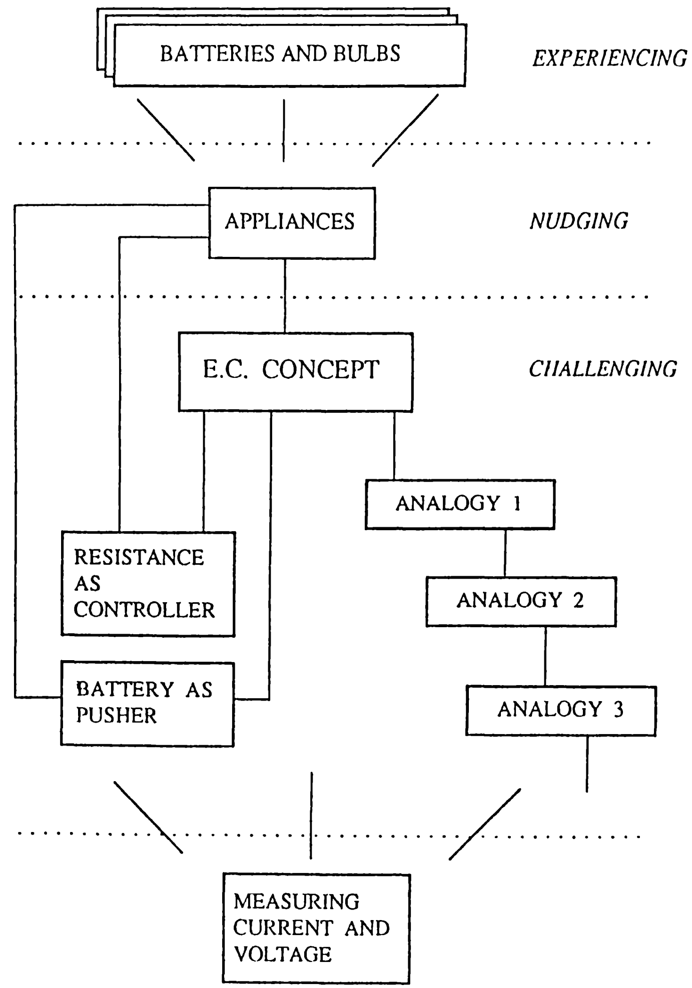
1. To explore different valve settings and try to predict what will happen before trying a new setting.
2. To compare with the electrical gear. Ammeters can be used in the circuit and their readings compared with flow numbers.
3. To start learners thinking about the water rubbing against the sides of the pipes and the flow-watchers (friction) and compare with the consumption-carrier model and the computer simulation.
4. To find answers for these questions:
   Which valve settings would flatten the 'battery' quickaet?
   Which valve settings would flatten the 'battery' slowest?
   Why?

The water model helps to develop the idea of the circuit as one complete system rather than individual parts or components, that is, to to develop systems reasoning in place of linear reasoning.

3.4 AN OVERVIEW OF ELECTRICITY TOPICS

If it was an ideal world we would like to see this progression:

Primary School	Batteries and bulbs torches Morse code switches.	Two or three times from new entrants to standard four. *Experiencing*
Form 1 and 2	Thinking about how a simple appliance works; e.g. toaster hair drier clothes iron electric jug.	Once or twice. Developing ideas about current, resistance and heat. *Nudging*
Form 3	Clarifying the electric current concept.	Four to five weeks. Developing models and analogies. *Challenging*
Form 4	Minor topic resistance and volts.	One week. Refining analogies and ideas.
Later	Measuring amps and volts.	A new metaphor.



Appendix 4.2: A ten-point survey.

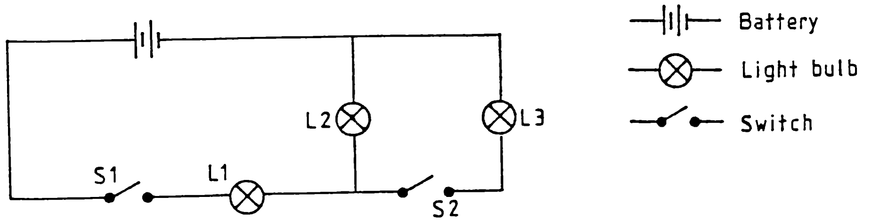
Name:.............................. Class:.............

School: ....

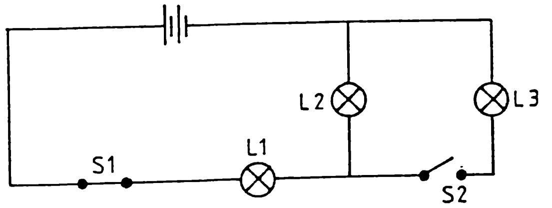
This survey looks into some of the ideas you have explored in the unit on electric current. Read each question carefully, and when you have decided upon your answer, write it down. Then try to say why you think your answer is correct.

The first two questions apply to the following information:

In the electrical circuit drawn below, each of the light bulbs in the circuit is the same as the other.



1. Switch S1 is closed and S2 remains open



In this case,

a) None of the light bulbs light up.

b) Bulb L1 only lights up.

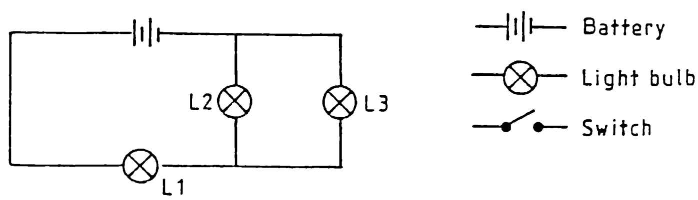
c) Bulb L1 and L2 only light up.

d) All of the bulbs light up.

Answer: ......

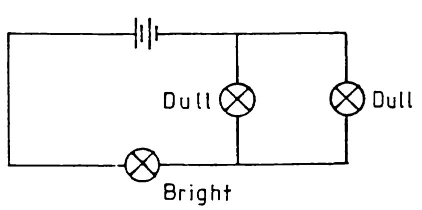
Reason: ....
....
....

2. Switch S1 and S2 are both closed, and all the bulbs are glowing.

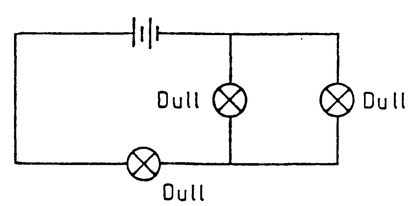


The brightness of the bulbs are best shown by which diagram?

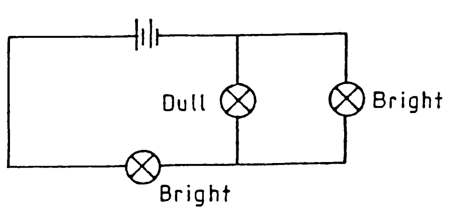
A



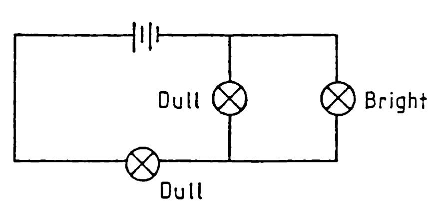
B



C



D



Answer: . . .

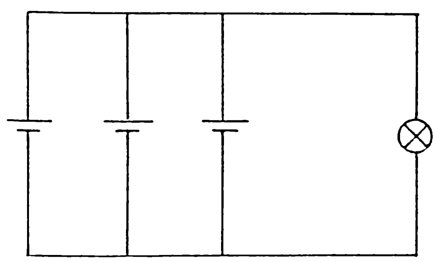
Reason: . . . .

. . . .

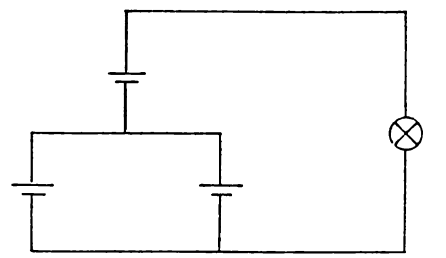
. . . .

. . . .

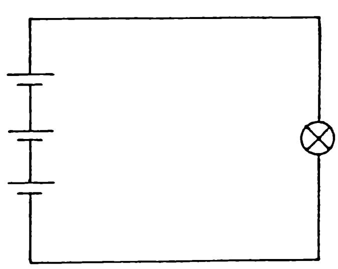
3. In the following circuits all the batteries and bulbs are the same. Which of the bulbs would glow most brightly?



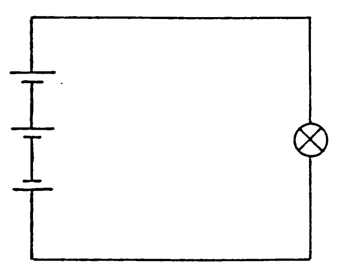
A



B



C



D

Answer: ....

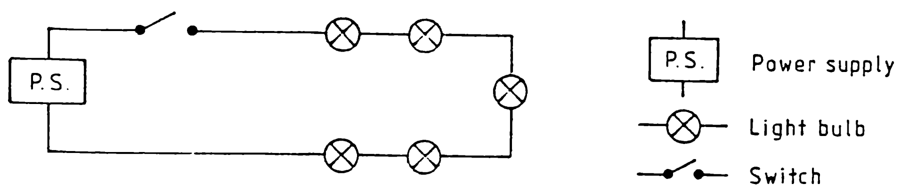
Reason: . . . .

. . . .

. . . .

. . . .

4. The diagram below represents an electric circuit containing five light bulbs connected to a power supply.



If the lights are switched on and then one bulb filament burns out the rest of the light bulbs will,

a) go out,

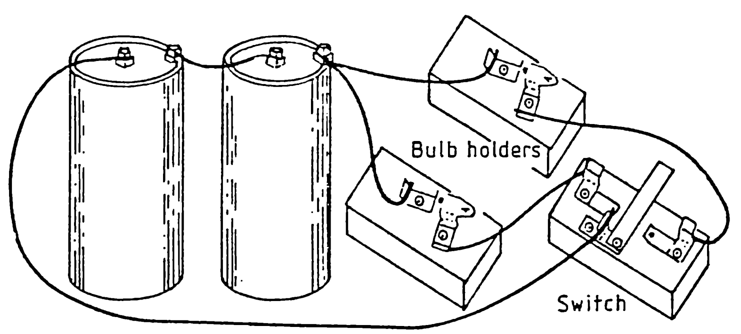
b) glow more brightly,

c) glow less brightly,

d) remain the same brightness.

Answer: ....

Reason: . . . .

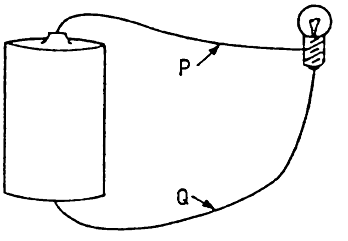


Turn this circuit, shown above as it actually appears, into the electrician's code.

Draw your answer in this space

The following information is for questions 6 and 7

A battery is connected to a torch bulb.



6. The bulb is glowing. There is an electric current in the wire marked P. Which is the best sentence about the electric current in the wire marked Q?

   a) There is no electric current in wire Q.

   b) There is some electric current in wire Q, but less than in wire P.

   c) There is the same electric current in wire Q as in wire P.

   d) There is more electric current in wire Q than in wire P.

   Answer: ....

   Reason: . . . .

   . . . .

7. Which of the following is the best sentence about the direction of electric current in the wires?

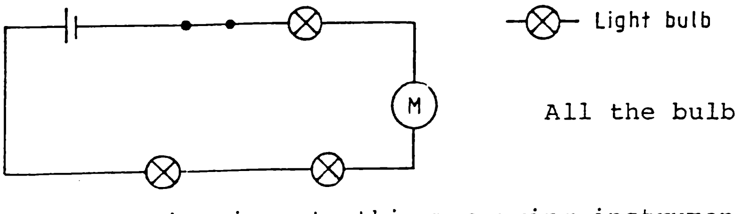
   a) The current goes from the battery to the bulb in one wire but there is no current in the other wire.

   b) The current goes from the battery to the bulb in both wires.

   c) The current goes from the battery to the bulb in one wire and from the bulb to the battery in the other.

   Answer: ....

8. In the circuit below, the symbol "M" indicates a measuring instrument.

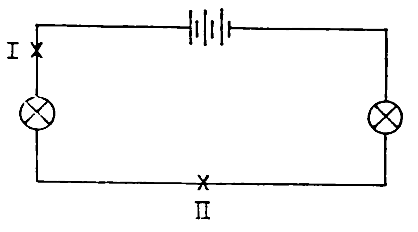


All the bulbs are glowing

What name is given to this measuring instrument?

. . . .

9. A student made up an electrical circuit with a battery and two light bulbs linked in a line, as in this diagram.



The light bulbs are identical. The positions marked with a cross, and a numeral, I and II, are places where this student put a meter to measure the current flow.

When this student measured the current at I, she found that the meter indicated 650 milliamps (650 mA). If the same meter was then put at II, would it then read

a) more than 650 mA,

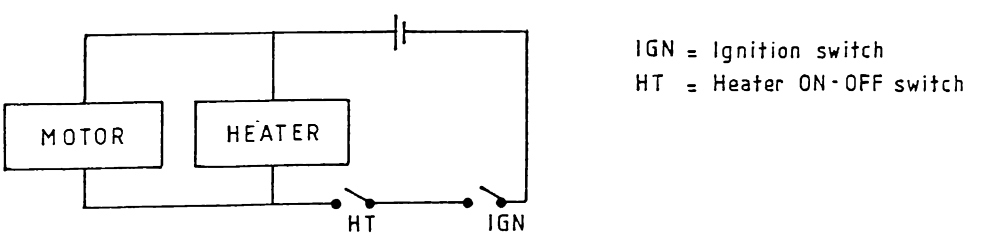
b) 650 mA,

c) less than 650 mA.

Answer: ....

Reason: . . . .

10. Jill was examining Jim's answer to the problem about a car's heater switch. Jim's answer was



Jill thought that there was something wrong with this answer. Can you suggest what Jill was concerned about?

. . . .

. . . .

. . . .

Can you suggest an improvement?

Draw your answer here.

Appendix 5.1: The 11-year-old group - some information offered by their teacher.

After the familiarisation phase, the teacher reduced the group to 15 so that she could work with the other 20 learners on different curriculum material. The group selected contained some of the academically advanced learners, and some who were not. The teacher identified four learners from this category when asked later by the researcher to say how she had decided on the membership of the group.

Her records on this were:

For the interest shown in the topic and because of surprising performances and attitudes in the familiarisation phase, the following were selected-

Ivan — *while normally of erratic behaviour and poor work habits, Ivan maintained his interest, showed confidence and practical understanding. He has been assertive but does not work well in groups.*

Eldon — *easily distracted, short concentration span, in remedial reading group; but (here) Eldon has worked thoughtfully and very keenly during this unit so far; he is usually hesitant but he spoke fluently and confidently on this topic.*

Conway — *a quiet, self-conscious boy with limited reading ability, he has concentrated and discussed animatedly and shown an understanding well beyonf his usual level.*

Natasha — *has great difficulty retaining facts, but is of bright and vivacious nature; she made an excellent oral contribution showing real interest and enjoyment in this approach.*

Standardised information about this group was available in vocabulary, comprehension, listening and mathematics. The percentile rankings for these categories are reported in Table A5.1.

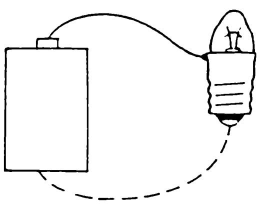
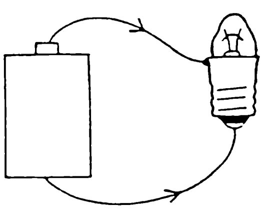
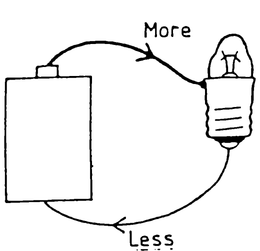
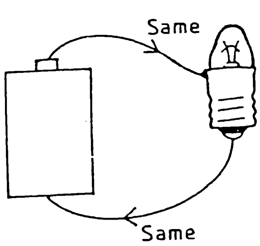
Table A5.1: Standardised percentile rankings for four learners.

Name	vocabulary	comprehension	listening	mathematics
Eldon	22	63	40	2
Ivan	36	63	40	17
Conway	na	na	46	0
Natasha	16	19	35	2

Key na = not available

Appendix 5.2: Survey 1 used in trial 2.

Different people have different ideas about electric current. Some of these ideas are summarised by these diagrams, in the table below.

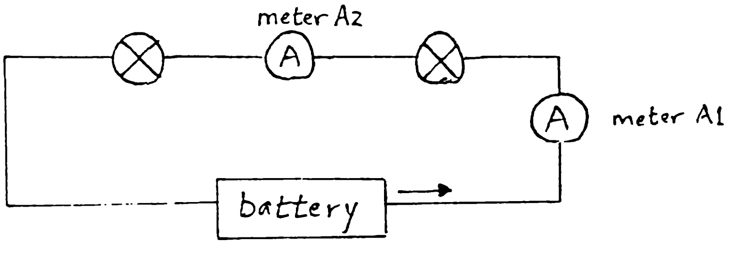
	DIAGRAM	EXPLANATION	EVIDENCE
A		"There is nothing in the return wire, but it is needed."	
B		"Each wire has a current and they clash inside the bulb; the current goes from the battery in each wire."	
C		"The current goes round but less comes back than goes out from the battery."	
D		"The current goes round, and the same amount of current returns to the battery."	

In the EVIDENCE column, write what you think is the best evidence FOR or AGAINST each idea shown by these diagrams.

Appendix 5.3: Survey 2 used in trial 2.

ELECTRIC CURRENT PROJECT - SECOND SURVEY

In this circuit, the current flows from the right hand end of the battery.

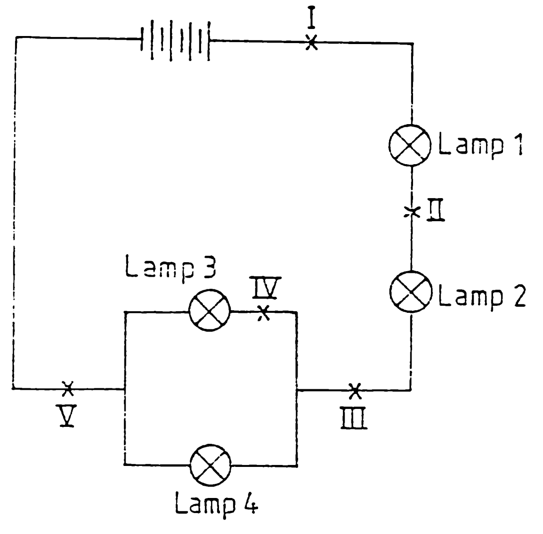


The ammeter (meter A1) indicates a current of 510 milliamps.
Would you expect the second ammeter (meter A2) to indicate

(a)	less than 510 mA?	YES	NO
(b)	exactly 510 mA?	YES	NO
(c)	more than 510 mA?	YES	NO

Explain your choice as fully as you can in the space below.

Appendix 5.4: Survey 3 used in trial 3.



I, II, III, IV, V are points on the circuit.

Lamps 1, 2, 3, 4 are all identical.

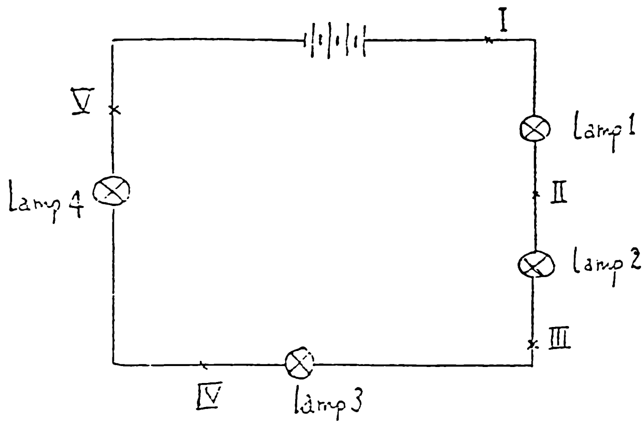
Q. Where in this circuit, is the current the least?

(P) I
(Q) II
(R) III
(S) IV
(T) V

Why do you say this?

Appendix 5.5: Survey 4 used in trial 4.

A student made up a circuit consisting of a battery and 4 lamps linked in a line, as in this diagram.



The lamps are all identical. The positions marked with a cross, and a numeral, I, II, III, IV or V, are places where this student put a meter to measure the current flow.

When this student measured the current a I, she found that the meter indicated 650 milliamps (650 mA). She then asked the other students in her group, Janet, Mary, and Ann, to predict what the meter would indicate at the other 4 positions.

Janet's prediction:

The meter would indicate the same at II and III, but would be less at IV and V.

Mary's prediction:

The meter, at position II, would indicate the same as at position I, and at III, and IV, and V.

Ann's prediction:

The meter would show the biggest reading at I, a little less at II, still smaller at III, less at IV than at III, and the smallest of all at V.

Do you agree with any of these predictions?

Would you make a different prediction?

Write about your predictions...

(use the back of this sheet)

INTRODUCTION

This workbook on electric circuits will help you to keep records of the things you do in this unit. While you are working through the material in this workbook, you should think about what is happening in the electric circuits you will make.

The purpose of this unit is to explore the ways people think about 'electric current'. In the first part you will find out how to make simple circuits, how to describe them, and you will become a Morse Code operator. In the second part of this unit, you and your classmates will consider your views on how you think about an electric current. Finally, you will meet a set of interesting practical problems and you can try to solve them.

Remember that the purpose of this unit is for you to form a view of what an electric current is.

SAFETY

Becuase you will be dealing with electrical equipment in this unit, you must decide on a set of safety guidelines to work with. Scientists take particular care to make sure that their equipment is safe to use, and that it will not harm other people.

Summarise your class safety rules.

1 Keep equipment away from water

2 Keep an eye out for danger signs e.g. sparks, wires

3. Dont fiddle with or try to mend appliances. Turn off first before examining

4 Dont overload plugs

5 Test suspect equipment with the back of hand

Electric Shock Victims

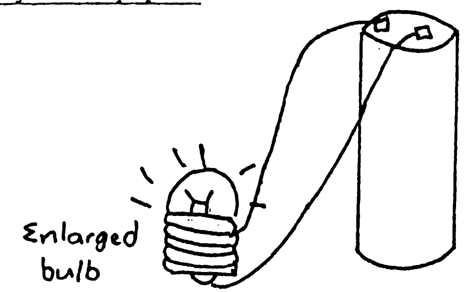
1 Isolate from wires 2: Resuscitate 3. Treat for shock:

MAKING THE LIGHT BULB GLOW

Obtain a No. 6 cell (you would call this a battery, but it is better to call it a cell), a bulb holder and bulb, and two plastic coated wires.

Use this equipment to make the bulb glow.

Diagram of Equipment



TESTING THE BULB AND THE CELL

Sometimes you find that the bulb will not glow, even though you have put the equipment together in just the same way as everybody else. What went wrong? Maybe the bulb has 'blown'. It is difficult to see the filament in a tiny bulb, so you have to find a better way of testing the bulb. How would you do this?

We wired the bulb, battery and ammeter up to see if the light shined and how far the needle moved on the ammeter. The needle moved if a current was flowing

Perhaps the cell is 'flat'. How would you find out?

Test on a vault meter. Ours reads 1.6 volts on the Voltmeter

THE MORSE CODE

The electrical circuit which you have made can be used to send Morse signals.

Samuel Morse devised the Morse Code in 1838, about 40 years before Bell invented the telephone. This Code made it possible for people to communicate directly with one another over very long distances. In this Code the 26 letters of the alphabet are represented by 26 different sets of long and short dots and dashes. When you send a message in Morse, make your dashes three times longer than your dots.

A	.-	N	-.
B	-...	O	---
C	-.-.	P	.--.
D	-..	Q	--.-
E	.	R	.-.
F	..-.	S	...
G	--.	T	-
H	....	U	..-
I	..	V	...-
J	.---	W	.--
K	-.-	X	-..-
L	.-..	Y	-.--
M	--	Z	--..

A Morse message which is quite famous is

S O S
... / --- / ...

Do you know what it means?

You could send a message to your classmates. Write it in Morse in the space below.

MORSE MESSAGES

Turn this message into Morse

IS IT EASY TO LEARN A NEW LANGUAGE.

Can you translate this coded message?

../...//../-//./.-/.../../././.-.//---//-.-.---

-.././/---/.-.//---//-.././-.-.---/-.././/

Is it easier to code or decode

And this?

.--/..../---/..././/-.../../.-./-/..../-../.-/-.--//

../...//../-//-/---/-../.-/-.--//

Whose birthday is it today

Who was Mr Morse?

.../.-/--/..-/./.-..//--/---/.-./.../.// Samuel Morse was

.--/.-/...//-.../---/.-./-.//../-.//.-/--/./.-./../ born in Americ

-.-./.-//../-.//..-./.-./.-/-/././-.//-/../-/././-/ in 1791. He

---//---/-././/...././/../.../-.-/-.---/--/-.// is known as

.-/...//-/...././/../-./...-/./-./-/---/.-.// the inventor

-/...././/-/./.-../.--./.-./.-/.--./....// of the telegraph

Can you find out more about Samuel Morse?

What do these words mean?

telegraph, telegram, telephone, teleprinter, television, telescope.

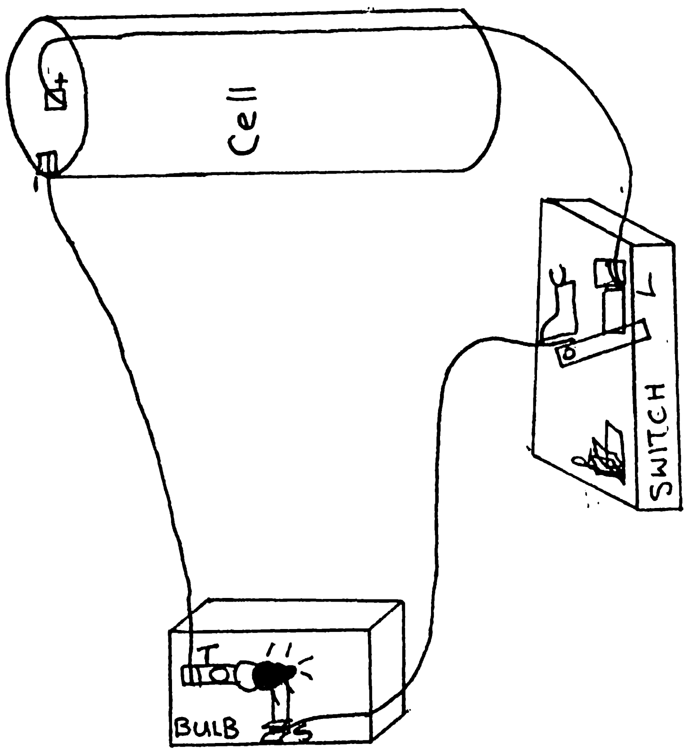
telegraph: (apparatus for) transmission. of. messages. to. a. . distance. by. making. and. breaking. electrical. connection.

telegram: message. sent. by. telegraph. telephone: apparatus for. transmitting. speech. to a. distance. communication.

teleprinter: telegraph instrument for sending messages,

DRAWING THE EQUIPMENT

Use this page to draw a picture of the equipment you have used to send Morse signals. Try to make your drawing as accurate and exact as you can.



by typing <u>television</u>: system for reproducing actual or recorded scene with sound at a distance on screen etc. <u>telescope</u>: optical instrument using lenses or mirrors to make distant objects appear nearer and larger

DESCRIBING THE EQUIPMENT

On this page write about the equipment you have used to send Morse signals. You could imagine that you are trying to tell another person, who has not seen this equipment, how he/she could make a Morse signal sender.

The equipment you need is a cell or battery, a switch, a bulb and several wires with the insulator removed from each end leaving the inside wires exposed. Take a wire and place it under the little screw of the negative terminal on the cell. Connect the other end to 'T' on the bulb. Take another wire and connect it to 'S' on the bulb and the other end to 'C' on the switch. Lastly you need one more wire which you attach to 'L' and the other end under the positive terminal of the cell. You now have a complete circuit and using the switch may operate in morse code.

Refer to diagram

EXTENDING THE SIGNALLING EQUIPMENT

Your task now is to think of different ways to extend the signalling equipment. You could include a switch, more lights, longers wires, and more cells. Write about what you try, and note any interesting ideas other students suggest.

We did several different circuits and found that if we had two cells and one bulb the light was very bright because there is energy from two cells going into one bulb. When we had two cells and two bulbs the light wasn't as bright because more energy was needed for two bulbs.

USING A CODE TO DESCRIBE THE EQUIPMENT

On pages 6 and 7 you made a drawing and wrote a description of your equipment. Many students find that these methods are time-consuming, and it is hard to get them exactly correct.

One student has devised a shorthand which you may find helpful. This student wrote:

1. – ⟶ BULB T,
BULB S ⟶ + .

Can you make a circuit from this instruction? Then try this -

2. – ⟶ BULB T,
BULB S ⟶ SWITCH C,
SWITCH R ⟶ + .

You will have found that this is a very effective way of writing about an electric circuit, because it is simple, brief, and clear. Everybody can understand it.

Now try some more complicated circuits. As you make each of these circuits, write down, in words, what happens to the bulb.

3. – ⟶ BULB 1 T,
BULB 1 S ⟶ SWITCH C,
SWITCH L ⟶ BULB 2 T,
BULB 2 S ⟶ + .

A very faint light in the bulb occurs. Bulb 2 stronger than Bulb 1.
2nd attempt - Both lights the same but dim.

4. – ⟶ BULB 1 T,
BULB 1 S ⟶ BULB 2 T,
BULB 2 S ⟶ SWITCH C,
SWITCH R ⟶ + .

Nothing happened unless we touched the bulb. The light was very dim but bulb 2 was brighter than bulb 1.

2nd attempt - Both lights were dim.

5. - 1 → - 2,
+ 2 → BULB T,
BULB S → + 1.

No. reaction. You cannot connect a negative to a negative.........

6. + 1 → - 2,
+ 2 → BULB T,
BULD S → - 1.

Bright light when touched..... otherwise nothing...............

7. + 1 → - 2,
+ 2 → BULB 1 T,
BULB 1 S → BULB 2 T,
BULB 2 S → - 1.

Bright light from Bulb 2 and... moderate for Bulb 1. We had to squeeze the bulb. Dimmer than No. 6.

8. + 1 → - 2,
+ 2 → BULB 1 T,
BULB 1 S → BULB 2 T,
BULB 2 S → BULB 3 T,
BULB 3 S → - 1.

This is a particularly interesting circuit. If you loosen any one of the bulbs so that its T contact is broken, what happens? Try it.

When one is loosened they all go out. Dimmer than No. 7

This is known as the "Christmas Tree Lights Problem". Does it happen with your Christmas tree lights too; when one bulb is defective, none of the bulbs can glow? Surely there is a better way of arranging the wires so that if one light is broken, the remainder will still glow? We will return to this problem later.

9. + → BULB T,
BULB S → SWITCH 1 C,
SWITCH 1 L → SWITCH 2 R,
SWITCH 1 R → SWITCH 2 L,
SWITCH 2 C → - .

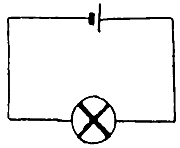
This is an interesting circuit, too. Can you find a circuit in your home which is like this? Could you find a use for this circuit?

In our house...2 switches in our lounge. You can turn it on & off at both. Good light showed When both switches on 'L' light didn't go. Same for 'R'. You have to have one on 'L' and one on 'R' for light to go.

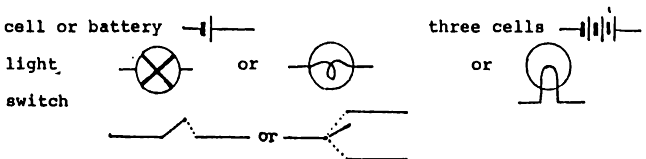
THE ELECTRICIAN'S CODE

The code that you have been using in the 9 circuits on the previous pages is a useful code, because it helps you to build circuits. It is called a constructor's code. There is another code for describing circuits. It goes like this:

Circuit (1)



Electricians, engineers and scientists use this code. Its symbols are:

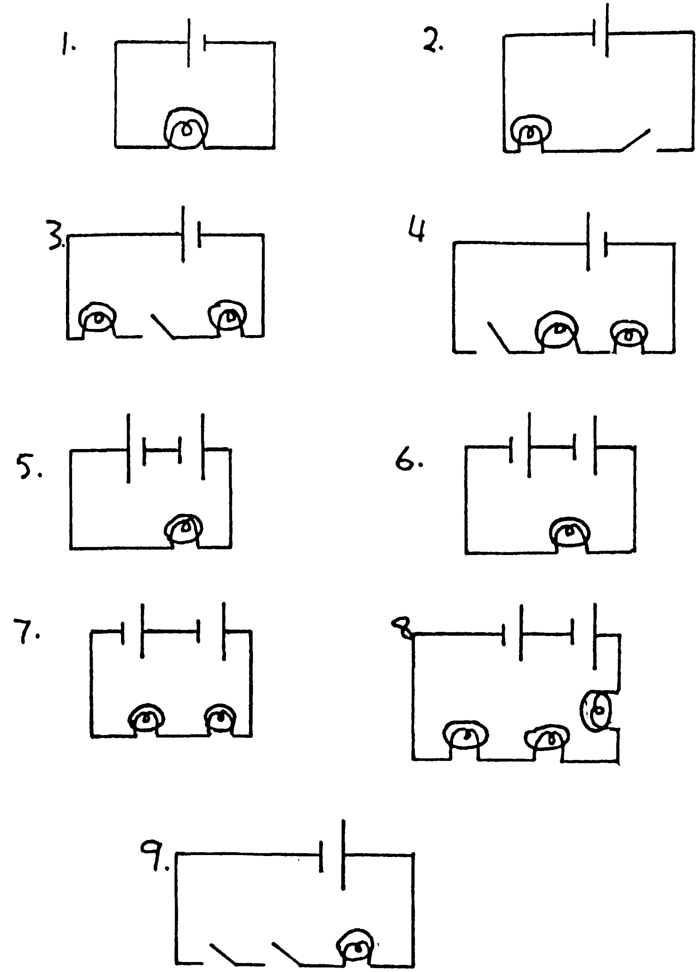


On the rest of page 12, and page 13, draw the electrician's codes for the circuits numbered (2) and (9) on the previous pages. When you have finished these, check your drawings with those of others in your class, and with your teacher.

Which of the 4 methods of recording - drawing, writing, constructor's code, and electrician's code, do you prefer? Why?

Of the 4 methods of recording I prefer the constructors code. I find it is the most easy or simple way to connect up a circuit. The letters or signs are on your switches and bulbs so all that you have to do is wire the circuit up correctly It is by far the easiest for me myself to understand.

ELECTRICIAN'S CODE, continued



SUMMARY - WHAT I KNOW ABOUT ELECTRIC CURRENT AND CIRCUITS

Use pages 14 and 15 to write down all that you know about electric current and circuits. Use information that you have gained from home and from school.

Safety - How to treat shock victims: move them off lines etc. Touch suspect equipment with back of hand. Look for danger signs

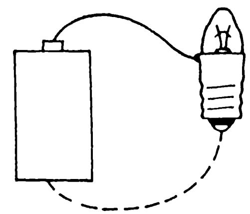
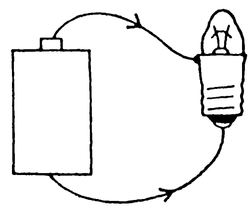
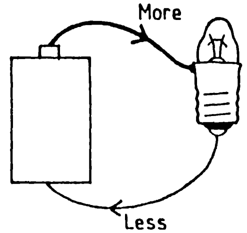
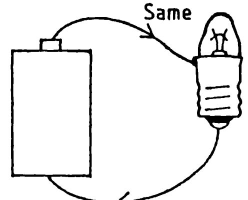
Morse Code - What the code is and that it is easier to decode than code. It is reasonably difficult to learn. You can make your own codes

Circuits - Wire cell to bulb to switch to cell. Join - to + on cells (when using 2 or more in circuit). When there are 2 or 3 lamps in a circuit they glow dimly. 2 way switch can control light. The more cells the brighter the lamps are. Some substances are conductors of electricity such as water. Rubber is an insulator. To check faulty equipment you can use a Voltmeter for a cell, and an ammeter for a bulb. With Christmas Tree lights if one bulb goes out all the others do too.

SUMMARY - continued

Language - Battery is called a cell. Lamp is a bulb etc. There are shorthand ways of recording circuits such as the Electricians Code and Constructors Code. There are symbols for components.

The next section of this unit on electric current and electric circuits is the THINKING part of the unit. You will realise that you know quite a lot on this topic, and the task now is find a simple, straightforward idea which will summarize all you know. How do you think about what is happening in an electric circuit? How do others in your class think about what is happening? How can we find out what is really happening? How do scientists think about electric current?

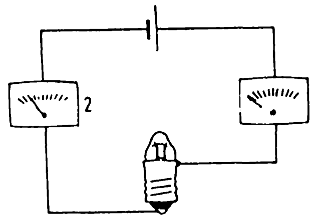
	My ideas	How others think	After the teaching	At the end of the unit
A 	I think this is incorrect. The bottom wire is needed and has electricity in it to make a complete circuit for the bulb to go.	0 Votes We all think there has to be electricity in both wires	I now think this is still incorrect because you have to have currents in both wires for the bulb to go.	This is definitely incorrect I have learnt that there is an amount of electricity in both wires to keep the bulb going continually
B 	I think this could be correct That you have electricity flowing from the positive & negative terminals to meet at the bulb.	9 Votes They think that there has to be an even flow in wires that both meet at the bulb and keep it going.	This is incorrect. For the bulb to go the current has to flow in one direction and be kept up with a steady amount of energy	I have also learnt that the electricity flows in one direction to be renewed at the cell after each round.
C 	In this one I think that there should be the same amount of electricity flowing from each terminal, not more or less	8 Votes They think that electricity is being used up by the bulb so less comes out the negative wire	In this one it is wrong because you have to have a steady flow which is renewed with energy after each current has been round the circuit.	This diagram is also incorrect I have come to the conclusion that the same amount of electricity flows all round the circuit
D 	This one I think is most accurate and shows a flowing electric circuit	12 Votes I havent changed my mind. I think that it is an even flow all the time to make the bulb go.	This is correct It is a steady flow with wires being renewed with charges at the cell.	I'm now positively sure it is a correct diagram of how an electrical current should flow to make the bulb go.

WHAT DO THE METERS INDICATE?

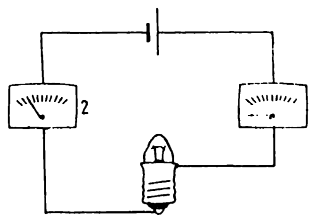
Write down what you think the meter on the right in the diagram will show if the meter on the left shows '2'. Then when you have seen what does happen write that down, too.

WHAT I EXPECT

A



B



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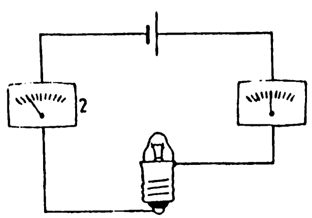
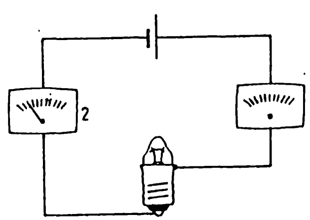
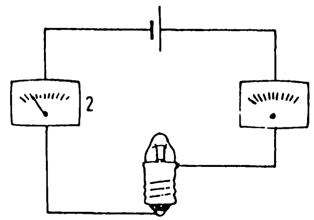


D

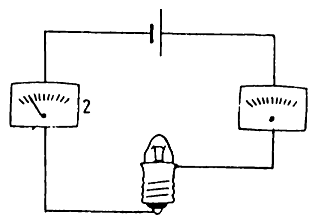


WHAT I SAW

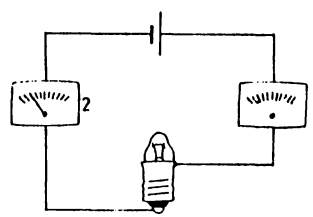
A



B



C



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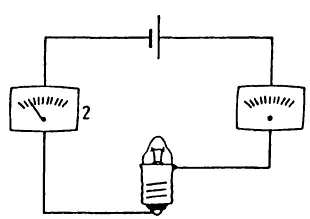


AIDS TO UNDERSTANDING THE SCIENTISTS VIEW OF ELECTRIC CURRENT

There are several ways of thinking about 'electric current'. You have seen four different ways. Oddly, the strangest of these is the way scientists think about 'electric current'. The evidence provided by the meter has to be right, but to most students it is an uncomfortable idea. You can become more comfortable about the scientist's view of electric current if you think about it in this way -

Imagine the electric current is a stream of motor cars. Each car has a driver. When the car goes to the cell or battery it picks up a passenger. Next the car goes to town. Here the passenger is put down, and the car, with its driver, returns to the cell, to pick up another passenger. And so on.

Maybe you could think about the cell as a supermarket. The cars arrive at the supermarket, the food is loaded, and the car goes home, where the food is unloaded. Next day the car returns to the supermarket, and so the process is repeated (until the supermarket runs out of food).

Your teacher will show you a simulation game in which people play the part of electrons, and tickets take the part of volts.

In these models, the things that move, the cars or the people, represent electrons. In the scientist's way of thinking, these represent the amps. The passengers in the cars, or the tickets carried by people, represent the volts. It seems that you must have both amps and volts to have an electric current. This is not as strange as it might sound. Again, a model might help you to understand this.

Think about a water-wheel in a pond. If the water does not flow, then the wheel cannot turn. If the water does flow, then the wheel will turn. And the wheel can turn faster if the water is made to flow faster - that is, if it is pushed more strongly. The 'push' is the volts, the rate of flow is the amps.

Electric Circuits
Problem 1

The Christmas Tree Lights Problem

Why is it when one light bulb goes out on a set of Christmas tree lights, all of the light bulbs go out?

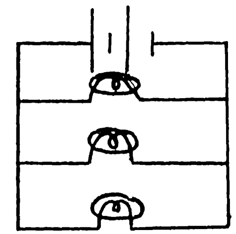
1. Can you connect up a set of three bulbs to show this happening? Loosen one of the bulbs until it is no longer in contact with its T plate. What happens?

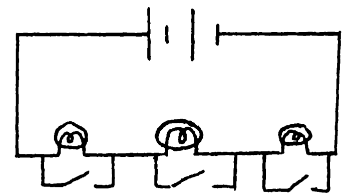
   When one bulb goes out so do all the others

2. This is a nuisance, isn't it? Perhaps there is a different way to connect three bulbs so that if one bulb is "out", the other two will keep going. Try to make this happen. Use this page to write down your answer to this problem. Write down the things that you observe, and also write down any less successful combinations of lights you tried. Use the opposite page for drawings and diagrams.

3. When you have finished this problem, talk to the teacher about your solution. Find out about other students' answers. After this, try problem 2.

Drawings for Problem 1:





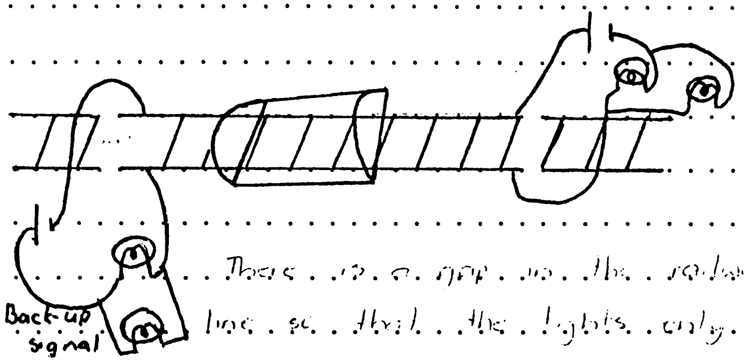
Electric Circuits
Problem 2

Keeping the Kaimai Tunnel Clear

How much did it cost to build the Kaimai Tunnel? No doubt you think it cost many millions of dollars. And, it did. It is vitally important that there are no accidents inside this tunnel, and you might be able to suggest a way that the Railways Corporation could use to find out if a train, or a carriage, or a truck was inside the tunnel. (The tunnel is too long to see through from one end to the other). You might be able to think of a way, using lights, which would tell the driver of a train approaching the tunnel that there is already a train, or a truck inside the tunnel.

Write your answer on this page. (You might find the 'railway tracks' a useful piece of equipment to have as you solve this problem).

Talk to your teacher about your answer.



There is a gap in the railway line so that the lights only go on when the train is in the tunnel. There are two separate circuits one at each end or otherwise you would have to wire each together all through the tunnel. There is a back up bulb in case one bulb blows out. It is done in parallel so that electricity will still flow around the circuit when one bulb goes out but the other will keep going

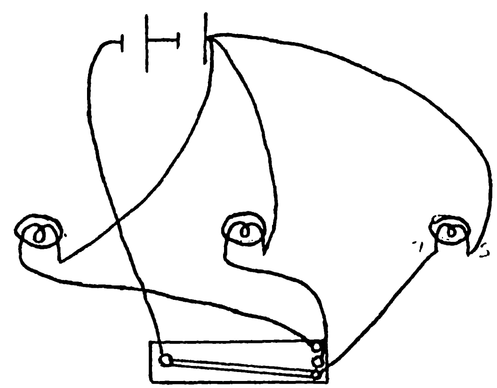
Electric Circuits
Problem 3A

Traffic Lights

Engineers who look after the roads in a town sometimes use traffic lights to control the flow of cars and trucks (and bikes) at busy intersections.

You could try to make a set of traffic lights, with three of the light bulbs in the electrics kit. There are lots of ways of doing this, and your teacher is interested in how you would go about this. Make a set of lights, and write down how you made it.

Wire up a switch to 2 batteries. Wire the other end of the switch to a light bulb and back to the cell. Do the same for 2 more bulbs.


Switch

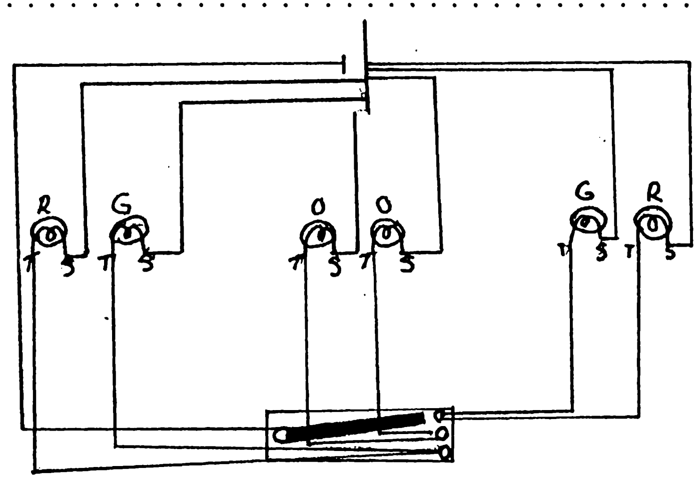
Electric Circuits
Problem 3B

Traffic Lights

Now that you have wired up a set of three lights to act like a set of traffic lights, you might like to extend your set of lights by adding three more lights to control the traffic on the road intersecting with the road controlled by your first set of lights.

When your light shows "green", the lights on the intersecting road must be "red" - this is a hint on how to wire up the lights.

Write about your answer. Talk to your teacher when you have solved this problem.



Electric Circuits
Problem 3C

Traffic Lights

So you're still interested in traffic lights? Good. There are many things you can learn, and many problems you can solve.

Here is one problem. How can you colour each of the lights in your sets of lights so that the bulbs glow 'red', or 'amber' or 'green' instead of white?

Your solution...

Electric Circuits
<u>Problem 4</u>

Doctors' Call Code

In some hospitals, there are panels of lights in the corridors. Each doctor in the hospital has his/her own pattern or code that lights up when the telephone operator wants the doctor to phone in.

Can you make a panel of three lights so that seven different doctors each has a different code?

How many lights would you need to provide each member of your class with a personal number?

This number system is called a binary code, because each of the lights can be in either the "on" or the "off" position. Do you know of other devices which use binary numbers?

Describe your set-up here, then tell your teacher about it.

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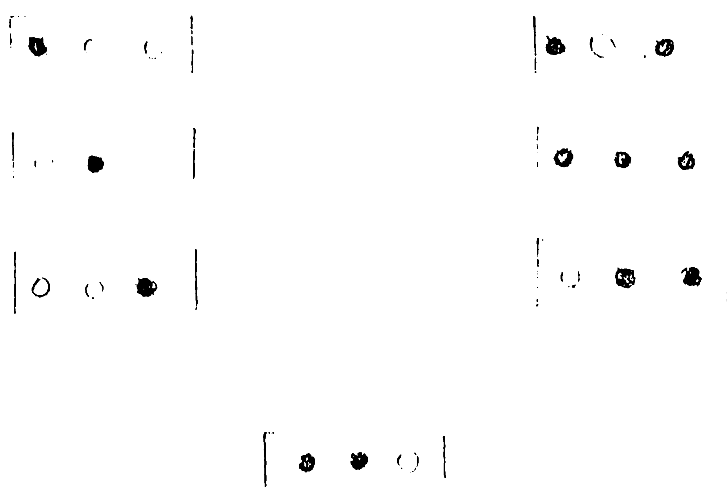

Electric Circuits
<u>Problem 5</u>

Car Heater Switches

In many cars, the heater can be turned 'on' when the ignition key switch is in the 'on' position; there are two switches. Can you imitate this type of circuit, using the light bulb to represent the heater?

Write your answer here, then talk to your teacher about it.

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Electric Circuits
Problem 6

A Lighting System for a Mine or a Tunnel

Can you build a set of four lights so that when you go into a mine, you turn the first light on, then when you have walked about 30 metres, say, you turn off the first light and at the same time, turn on the second light? In this way you put on the light in the part of the mine you are in. Then on going further into the mine, you turn off the second light and at the same time turn on the third light.

This seems to be a complicated problem, but it can be solved if you think about it. Try to make this arrangement of lights and switches, then record your answer, and tell your teacher about it.

Drawings for Problem 6.

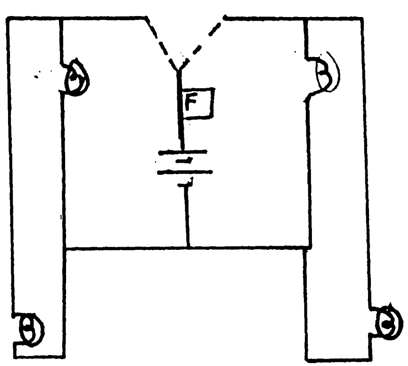
Electric Circuits
Problem 7

Car Indicator Lights

When a car driver flicks a switch to show that he intends to turn his car to the left, the indicator lights known as LEFT FRONT and LEFT REAR flash on and off. And if he had decided to turn to the right, by flicking the switch in the other direction, the RIGHT FRONT and RIGHT REAR indicator lights would flash on and off.

Can you imitate this using one switch and four lights? You will not be able to make the lights flash on and off yet, but you might have some ideas on how this could be done.

Write down your system, then tell your teacher about it.



Electric Circuits
Problem 8A

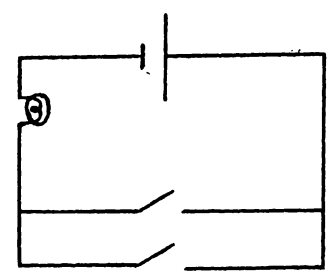
A Visitor at the Door

Some homes have a set of door chimes in the hall, with push-button switches at the front and back doors. If you can borrow a bell, you might be able to connect two switches (representing the front door and rear push button switches) to this bell.

How would you do this? Make it work, write down how you did this, then tell your teacher.

2 cells 2 switches 1 light

This is set up as a 2 way switch



Electric Circuits
Problem 8B

A Visitor at the Door - Helping a Deaf Person

In problem 8A, you built a bell system for the front and back doors of a house. Now, how could you modify this set up for the home of a deaf person? You could use a light in place of the bell.

Let's make the problem more interesting.

1. If only one person in the house is deaf, then a system which turns on both the bell and the light would be desirable. Can you do this?

2. Can you modify the system using a light so that the deaf person in the house can tell, by looking at the bulb, that the visitor is at the front door or the back door?

Write down how you did each of these, then tell your teacher about them.

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Electric Circuits
Problem 9A

Changing the Speed of an Electric Motor

1. Obtain a small electric motor from your teacher. Using a 1.5 volt cell, make it operate.

2 Can you now reverse this, so that the shaft rotates in the opposite direction? (Use the idea of clockwise, and anti-clockwise - when you are looking at the motor from the shaft end - to describe the direction of turning).

The method used. For this we changed the wires around on the motor to make it change direction.

3. Make the motor turn faster than it did with a 1.5 volt cell.

We used two cells to give more energy to the motor to make it go faster.

4. Make the motor turn more slowly than it did with a single 1.5 volt cell. Your model for electric current will help you to make predictions.

By loosening the wires you can make the motor go slower. You can also wire up a bulb to it because it uses up some power.

Electric Circuits
Problem 9B

Electric Motor

5. The methods of changing the direction of turning for electric motors are useful for people who design lifts and cranes. The problem now is to find a way to do this with a switch. Can you think of a way that a switch could be used to change the direction, from clockwise to anti-clockwise?

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6. Questions to think about.

How fast is the motor turning when it is linked up to two 1.5 volt cells? The makers of the Johnson 150 motor claim that, when there is no load on the motor, its speed is 9500 rpm (revolutions per minute). How would you check this measurement?

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Drawings for Problem 9A and 9B

SUMMARY AND EVALUATION

Now that you have completed this unit on 'electric current', it would be worthwhile to turn back to the table on pages 16 and 17, and to complete the final column. Make sure you write down your own view, the view you now have, of an electric current.

The teachers who prepared this unit on electric current are interested in your opinion on the things you have studied in this unit. Use this page to write about the things that you most enjoyed, and the things that you least enjoyed. If you would like to make some other comments, please write them here, too.

I still find it hard to understand electric currents because there are so many problem that you have to consider and how to wire up a circuit correctly You really have to think about what you are doing. This unit however has made it a little more clearer.

I found it much easier to wire a circuit after I had learned the constructors code and electricians code. These were a great help. The morse code was also fun.

When it came to the actual problems I found this was the most difficult task in this unit. The answers just didn't pop into your head

Appendix 6.1: Survey data from class 5Sci.1.

Name	Score for each question										Total	Model
Matthew Wa.	2	2	0	2	0	0	2	1	2	3	14	C-O-D
Karl S.	2	2	0	2	2	2	2	1	2	3	18	D-O-D
Hamish C.	2	0	2	2	2	2	2	1	2	3	18	D-O-D
Chris C.	2	2	2	2	2	2	2	1	2	2	19	D-O-D
Stephen H.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Chris H.	2	0	2	2	2	2	2	1	2	3	18	D-O-D
Michael F.	2	2	0	2	2	2	2	1	2	3	18	D-O-D
Tony H.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Simon O.	2	2	2	2	2	1	2	1	2	3	19	D-O-D
Jason M.	2	2	0	2	0	2	2	1	2	3	16	D-O-D
Grant B.	2	2	0	2	2	2	2	1	2	3	18	D-O-D
Malcolm O.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Byron S.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Peter S.	2	0	2	2	2	2	2	1	2	3	18	D-O-D
Mark K.	2	2	2	2	0	2	2	1	2	3	18	D-O-D
Andrew W.	2	2	0	2	0	2	2	1	2	3	16	D-O-D
John S.	2	2	0	2	2	2	2	1	2	3	18	D-O-D
Glenn R.	2	2	0	2	0	2	2	1	2	2	15	D-O-D
Marcus S.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Paul M.	2	2	0	2	0	2	2	1	2	3	16	D-O-D
Michael M.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Justin B.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Tony F.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Andrew E.	2	2	2	2	2	2	2	0	2	3	19	D-O-D
Richard C.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Brent L.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Andrew I.	2	1	1	2	2	2	2	1	2	3	18	D-O-D
Tim W.	2	2	0	2	2	2	2	1	2	3	16	D-O-D
Simon G.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Christopher W.	2	2	2	2	0	2	2	0	2	3	15	D-O-C
Grant R.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Paul R.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Tony D.	2	2	2	2	0	2	2	0	2	3	17	D-O-D
Karl D.	2	2	2	2	2	2	2	1	2	3	20	D-O-D

n = 34, $\bar{x}$ = 18.3 (91%), s.d. = 1.8 (9%).

Appendix 6.2: Survey data for Class 5Sci.2

Name	Score for each question										Total	Model
Richard T.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Nigel S.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Warren S.	2	2	2	0	1	2	2	1	2	3	17	D-O-D
Richard V.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Ben T.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Colin V.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Vince L.	2	2	2	2	2	2	2	1	0	3	18	D-O-C
Russ S.	2	2	1	2	0	2	2	1	2	0	14	D-O-D
Errol R.	0	2	2	0	1	2	2	1	2	1	13	D-O-D
Campbell S.	2	2	2	0	1	2	2	0	2	2	15	D-O-D
Steve T.	1	2	0	2	1	1	2	1	2	1	13	D-O-D
Tiny v-H.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Colin W.	2	2	0	0	1	1	2	1	2	3	14	D-O-D
Jason W.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Alan S.	2	2	2	2	1	2	2	1	2	3	19	D-O-D
Blair S.	2	2	2	0	1	2	2	0	2	1	14	D-O-D
Colin S.	2	2	2	2	1	2	2	1	2	3	19	D-O-D
Stewart C.	2	2	2	0	1	2	2	1	2	3	17	D-O-D
Brett S.	2	2	2	0	2	0	2	0	2	3	15	C-O-D
Lindon S.	2	2	2	2	2	2	2	0	2	3	19	D-O-D
Mark L.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Arron T.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Grant W.	2	2	2	0	1	2	2	1	2	3	17	D-O-D
Aaron W.	2	2	0	0	1	2	2	1	2	3	15	D-O-D
David W.	2	2	2	2	1	2	2	1	2	0	16	D-O-D

n = 25, $\bar{x}$ = 17.4 (74%), s.d.= 2.5 (12.5%).

Appendix 6.3: Survey Data for Class 5Sci.4

Name	Scores for each question										Total	Model
Ian J.	2	2	2	2	1	2	2	1	2	3	19	D-O-D
Rex G.	2	0	0	0	0	0	2	1	0	0	5	C-O-C
Ross C.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Ian H.	2	2	2	2	0	2	2	1	1	3	16	D-O-D
John K.	2	2	2	2	1	2	2	1	2	2	18	D-O-D
Chris G.	2	2	2	2	0	2	2	1	2	3	18	D-O-D
Karl G.	2	2	0	2	1	2	2	1	2	2	16	D-O-D
Greg K.	2	2	2	2	0	2	2	1	2	3	18	D-O-D
Arvind M.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
Tony M.	1	2	2	2	1	2	2	1	1	3	17	D-O-D
Craig H.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
David H.	2	2	2	0	2	2	2	1	2	3	18	D-O-D
Robert B.	2	2	2	2	1	2	2	1	2	3	19	D-O-D
Martin K.	2	2	2	2	1	2	2	1	2	3	19	D-O-D
Fred. E.	2	2	2	2	2	2	2	1	2	3	20	D-O-D
David M.	2	2	2	2	2	2	2	1	2	3	20	D-O-D

$n = 16$, $\bar{x} = 17.7$ (88.5%), s.d. = 3.6 (17%).