Students' Conceptions of simple D.C electricity circuits: A Study of primary, inappropriate conceptions, learning difficulties of Physics students, and Implications for Instruction:

THESIS

Submitted in Fulfilment of the
Requirements for the Degree of
Doctor of Philosophy
of Rhodes University

by

ZINDLOVU JIYA

December 1988

Abstract

The work attempts to identify the general conceptual problems of the generations of Black students who pass through first year physics courses at the University of Fort Hare. In particular the alternative conceptions of students in the area of direct current electricity are investigated, using various techniques including written diagnostic tests. The main method used in the investigation of the student frameworks is the personal interview. A varied number of inappropriate conceptions are identified in the students in significantly large proportions, and these are found to be dependent on many factors; for example the socio-cultural background like language and its metaphors, and media images. It is established that some of these are exacerbated by student perceptions about the nature of physics and of the scientific enterprise in general. Certain proposals are made about how to remedy the situation; relying mainly on the recently established innovative instructional strategies like conceptual change and cognitive conflict, and on making proposals about restructuring certain forms of presentation of the subject matter, paying attention to how language is used to address the specific problems of the students. The importance of providing practical experiences for the students is also emphasised.

TABLE OF CONTENTS

CHAPTER FIVE:

ADDRESSING THE PROBLEM

CHAPTER SIX

REINFORCEMENT OF APPROPRIATE CONCEPTIONS USING EXPERIMENTS

LIST OF TABLES, FIGURES

ACKNOWLEDGEMENTS:

I would like to acknowledge my indebtedness, and to express my appreciation, to many people and institutions, who in one way or another have made this study possible. In particular special indebtedness and recognition are due to Professor Hugh Helm who was the supervisor, for providing me with the guidance and advice; for his patience, the sharing of his ideas and time. My appreciations and thanks also go to Rhodes University, Professor Baart and the Physics department for accepting me to register for the PhD programme.

I am truly grateful to Hugh Helm for his inspiration and encouragement at the beginning; and his acceptance when I journeyed from the University of Fort Hare to ask him to supervise the work. His openness and friendliness have meant much to me. When he left Rhodes University I was able to keep in touch and followed him across the world to central New York state at Cornell University, and later on to Colgate University Hamilton N.Y. ; where I was received warmly by Mrs Helm every single time I showed up. I am thankful for the books, materials etc; which he willingly shared with me; for his original questionnaires some of which I used in the preliminary tests; his laboratory materials which I adapted for some of the remedial work on the inappropriate conceptions later on etc;. With his gentle criticism of my early thesis drafts he gave me thoughtful insights and counsel which helped me to isolate the real issues from the imagined ones.

The author acknowledges the University of Fort Hare for all assistance and cooperation especially during the experimental stages of the project. Special thanks go to the generations of students who I have taught first year Physics over the years at the University of Fort Hare; particularly those who sat for the personal interviews and agreed

to be guinea pigs. I hope that their younger brothers and sisters still coming on will get some benefit from this work. To them I would like to say: Mazenethole, Phambili MaAfrica. We are engaged in very important issues now.
Gratitude is also extended to Brown University, for acting as host to me during the final preparation of this work in the term beginning January 1988; and to the Educational Opportunities Council for making my overseas visit possible initially.

Finally, and most importantly, I would like to thank my family, my beloved wife Yaliwe; Lusanda, Loyiso and Busisa for their patient support and sacrifice during the entire preparation of this effort. I acknowledge a very special debt to my wife who as an academic, in many ways provided inputs into my work, and vital emotional support in many times of personal crisis.
I dedicate this work to this precious and wonderful family.

INTRODUCTORY CHAPTER :

This study was initially motivated by an awareness and appreciation of the difficulties and frustrations of the majority of students entering first year university physics courses in particular at the University of Fort Hare. Difficulties in the sense that they are unable to cope with their studies in any meaningful way; frustration in that they were not performing as well as they thought they could, and their success rate at the end of the year was usually not something that they could be proud of. On entering the university level course from school, their subconscious expectations are that rote learning is going to see them through at the end of the day, and I perceived them to be confronted and challenged immensely by the fact that they had to think more seriously and comprehensively about the underlying concepts of physics.

I have taught at secondary schools for quite a number of years. I started teaching at Lovedale high school in 1967 and was principal of a school in environs of Alice for four years. It would be pretentious of me if I did not admit that most of the problems of these youngsters arise largely from the circumstances at the schools level. There are numerous determinants here, and these can be isolated not only from the internal school's situation but also from outside it in the environment. My impression is that the conditions for learning science in black secondary schools are far from being adequate, for the average scholar. For example, I cannot recall ever coming across a school where there was a sufficient number of texts and an adequate provision of student laboratories. The complement of qualified teachers as a rule is neither enough nor satisfactory. In these circumstances free/lively and healthy debate on the science of teaching of the natural sciences is very rare, amongst the teachers. At its best this has taken the form of mere discussion about the relative merits of active versus passive student involvement with the learning process, and this in relation to the teaching of natural science and the use/need for science laboratories.

Tabled below are some statistics on the availability of teachers in the area in which the University of Fort Hare is situated, Ciskei, for the year 1986.

Some facts about the qualifications of Standard 10 Physical Science teachers:

Total number of Schools = total number of Teachers = 47

Qualifications		Total	
Academic	**Professional**		
Standard 10	with prof training	12	15
	without	3	
University degree B Sc or other	with	24	27
	without	3	
Post Basic degree Honours, M Sc	with	1	4
	without	3	
Not classifiable [from Ghana - chemistry Teachers Cert]			1
	Total No. of teachers		**47**

*By courtesy of Miss Qobo and Mrs Poho of the Ciskei Dept of Education

Of the total number of teachers with degrees only 7 were Physics majors; the other 19 had done only one year of university training in Physics. I would consider these the only really qualified teachers to handle standard 10 physical science. The best qualified teachers are always put in the standard 10 class, so the story is even bleaker for those classes below this level. The 16 schools (including one with B A degree), where the best qualification in Physical science for the teachers is a std 10, suggest that there is really no person qualified to teach physical science in those schools although the schools have opted to offer this subject.

My impression is that teachers at the secondary schools level , in the prevailing circumstances, perceive teaching as being the reasonable and straight forward matter of describing, as accurately as possible, (which never goes far as a rule) the operation of certain popular systems (particles in motion, car engines, thermometers, electrical appliances etc;) using language which is reasonably accessible to the scholar. The other activity is to demonstrate on the chalkboard the solutions of certain 'typical' prototype mathematically oriented physics problems. Laboratories, where they are available, are mostly still inadequately equipped and under utilised. In most forms of classroom activity the emphasis has not shifted from attempting to anticipate the examiner by trying to solve past national examination question papers. There is no attempt to provide the learner with some feeling for those elusive 'inner structures' of physical systems, the underlying conceptual structures of the discipline. The teaching and learning of structure, rather than simply the mastery of facts and techniques, seems to me to be at the centre of the classic problem of transfer. Grasping the structure of the subject is to understand it in a way that permits other things to be related to, meaningfully.

As a university lecturer of more than 12 years, I have monitored for several years the problems that beset first year physics students, and have been aware that too many of them fail to display my previously assumed conceptual level of entry to a university level course of study. I am convinced that the level of difficulty in science courses of these youngsters is matched to their preparation at the schools level. The inadequate preparation puts them at a significant, and distinct disadvantage. As I perceive them, the problems of students coming into university science courses can be grouped into three overlapping categories:

(i) Problems with basic concepts eg; force, energy, work etc;
(ii) Difficulty with scientific representations, including regular diagrams, graphs, mathematical formula etc;
(iii) Difficulties with scientific reasoning

At a closer look I have found that students have no satisfactory understanding of fundamental concepts like energy, charge, force, power, statement of conservation principles, instantaneous velocity, acceleration. Often they are not able to sort out the difference between mass and weight, and understand electric current to be (electrical) energy. Some reports at the local (Southern Africa) level have indicated conceptual problems not only at the schools level, (Helm 1980), (Hewson 1983), (Stanton 1986), (Whittles 1980), but also at the university level, where some in depth studies have already been undertaken (Helm 1980), (Hewson 1983), (Mehl 1983 and 1986), (Lindner 1983), (Seretlo 1980), (Stanton 1986). The problem of scientific representation is not primarily that of a lack of skills eg; those of plotting of graphs etc; but rather the inability to relate them in science problems. For example many students may be able to work out the slope of a graph, but are not able to say what information this provides about the system in question. Students may be able to solve algebraic equations but be unable to write the equation needed to solve a particular problem. They see the graphs, formulas etc; as having an identity of their own, instead of being directly connected with the relevant physical systems.

My impression is that most students find it hard to follow arguments especially when the reasoning is by analogy. Reasoning is critical to all sciences. Many concepts derive much of their meaning from particular lines of reasoning. For example, since the mass and volume of a substance are proportional, the concept of density relies heavily on proportional reasoning for its meaning. Concepts which are expressible as rates eg; velocity = ds/dt; acceleration = dv/dt are also very difficult. For most students as long as the body is moving it is accelerating. If its velocity is increasing in time then the acceleration is also increasing. It has become clear that many of the students have not developed the reasoning skills that are necessary for the understanding and retaining of physics concepts. It would seem that the problems of students are at least two fold; there is the apparent inability to undertake scientific reasoning effectively, and secondly what the consequences of this may be on how they may understand [or misunderstand] scientific concepts introduced to them, or even the nature of scientific knowledge.

In recent years the importance of reasoning in science education has been widely discussed in the literature in connection with Piaget's theory viz. that the development of the intellect passes through successive stages (Moose 1983) . In this theory, to be discussed more elaborately later, only the third stage (concrete operational) and the fourth stage (formal operational) are of relevance to university students. The ability to perform operations with ideas or representations is a characteristic of the stage of formal operational thinking. Some examples of formal operations are: forming and checking hypotheses, controlling variables (as in graphs), and reasoning with proportions or deducing logical implications. Evidence has been presented that many students including university students, are not able to do the reasoning required in their physics courses (Lin 1983), (Rosenquist 1983), (Mulopo 1983), (Moose 1983),. This problem appears to be universal.

Arising from the observations mentioned above, my feeling was that there was a need for:

(i) obtaining a more qualitative description of student difficulties when they enter university physics courses especially in the area of concept formation.

(ii) the design and construction of formal and informal teaching strategies to alleviate the problems of first year physics students.

The overwhelming feeling was that a very significant part of the problem lies in the area of pre-conceptions and misconceptions that students hold, on certain fundamental physics concepts, at the time that they enter physics courses at university level.

Within the past 10 years research in physics education has shown that many students enter physics courses with concepts about natural phenomena that disagree with those accepted by physicists [Clement 1983; Cohen et al 1983; Helm 1980; Maloney 1986]. Most of these ideas have been shown to be deeply rooted and need to be taken seriously. There has been discussion about the nature and origins of student conceptions and how these are learned from interactions with the life world [Solomon 1983] in which the child grows. Preece (1984) advances the hypothesis that these conceptions are not learned from experience as such but are triggered by it.

There is debate about whether some of these student conceptions may be regarded, at some stage, to be part of the students scientific knowledge. Solomon [1983] maintains that there are two knowledge domains in pupils, the life world and the scientific; that there is an urgent need to explore how the prior notions of science fom the life world interact with the science that we teach. Some of these pertinent issues will come up again in this work and I hope that they will be clarified to some extent by this research in so far as they infringe into its specific context.

At this point it is perhaps advisable to give some more precise definitions of the very important terms which will appear quite frequently throughout this thesis:

A conception may be explained as a person's unique construction of some idea of reality ie; it is something that is known by that person.

A pre-conception is understood to be any collection of factual and predicted outcomes based on prior specific actions or schema, found in a persons mind. This collection is used by that person to deal with some particular information outside that person's mind, [Fredette 1981] . Some pre-conceptions are deeper and more extensive than others; and we are more aware of some than of others.

Misconceptions are in some way like pre-conceptions, except that this label is reserved for those conceptions which are either incorrect or become inappropriate in time as a result of some educational experience presumably designed to create a 'true' or more appropriate comprehension. Naturally a most important set of pre-conceptions to an instructor is that of those which retard progress in the course of study. Of equal relevance also would be those firm and comfortable intuitive ideas which can be built upon in material to be introduced later on in the process of learning.

As indicated in the last paragraph, the term 'misconceptions' is generally used for those thinking models or ideas which lead to unacceptable answers (by the community of active scientists) or solutions to questions or problems in the context of a course of study. In this connection, it is important to note that, although the word misconsception carriers an 'error' connotation, misconceptions are not always undesirable or without use. They can in some cases be creations in the minds of students which are useful first order theories about physical systems around us. Probably, in the context of any standard physics course, however, they can be in conflict with the more formal and established theory that is being taught. Other terms for these test items, for example alternative frameworks, common sense theories, intuitive ideas etc; will come up in the next chapter on the literature review, and will be attended to accordingly. At that stage we will have a more comprehensive picture of the kinds of misconceptions that student have on natural phenomena, and how inappropriate these are.

The purpose of this particular investigation was to identify students' misconceptions in that area of the first year university physics content generally referred to as electricity. An emphasis was placed on obtaining a qualitative description of the significant students' pre-conceptions and misconceptions, rather than on establishing accurate proportions of students who had trouble with particular test items. It was hoped that with these in mind, some instructional strategies would evolve, that could be used effectively to remedy the inappropriate conceptions or to accommodate them, whichever seemed to be more appropriate. I had also hoped that the research findings could become relevant in some way in the further investigations of the correctness and usefulness of certain current practices in university physics education. Here I can think of the common practice of using words (from life world situations) for concepts, whose meanings transcend the commonsense meanings; for example force -as in electromotive force- when emf is by no means understood to be a force in the physics sense, the 'use' of energy when this implies that this energy dissipates/disappears etc;.

My experience is that most of the first year intake in black universities in this country, are youngsters who will do a single course in physics and will perhaps never meet up with any formal tuition in physics afterwards. Courses in physical science are a gateway to most science careers. These young men and women would then normally pursue careers in other fields of human endeavour like health sciences, engineering, other industrial technology etc; and it seemed to me rather important that they possess more appropriate notions of physical systems and concepts. As it turns out, a large number of these students become teachers of physical science in the schools. I have had the opportunity to supervise quite a number of these in the postgraduate education diploma year, when they were doing practice teaching. I have never stopped being astounded by the many and widely held inappropriate conceptions held by these student teachers. As a teacher I have been particularly concerned about this because, in this way, misconceptions are passed on to future generations of students.

I had the thought that it would be a worthwhile contribution to document something on inappropriate conceptions in electricity of black students who attempt physics courses at the University of Fort Hare. My suspicion was that I would find some incorrect conceptions amongst these youngsters in the area of elementary electricity. I had a feeling that the situation here would likely be influenced by the real life circumstances from which these students came, and exacerbated by the shortage of science school teachers and facilities in the black schools from which they had come. I was keen to compare my findings with those from other parts of the world where more extensive work had been done. Mostly I wanted to make some contribution to alleviating some of their problems which I had come to be aware of to some extent already. For example, I perceived some of their problems to arise because the electron flow, and the ways in which it manifests itself in electric circuit systems, are relatively more complicated and difficult to interpret in terms of the basic Newtonian mechanics they are familiar with. My impression is that students find it difficult to understand the manner in which charge is conceived to flow, and would rather think in terms of particles [electrons] flowing.

I hope that the findings of this research will be of benefit to science teaching and that in general it will be found to address boldy and effectively the genuine conceptual problems of the physics student at university and at school level.

CHAPTER ONE

AN OVERVIEW OF THE LITERATURE RELATED TO PRIMARY CONCEPTIONS STUDIES AND THEIR ROLE IN LEARNING

1.0 Introduction:

Studies relating to the nature of learning and the theories evolving from these have been with us from the time before education was made formal. A quick survey of this scene reveals that, whilst there is considerable unanimity in recognizing that learning is essentially change due to experience, different points of view have emerged regarding those aspects of learning which have the greatest theoretical and practical importance.

The early work of Locke supported the notion that we are what we are through experience, that a man's mind at birth is a blank sheet (a tabula rassa). The empirically based theories of Froebel, Herbart and others evolved into the Stimulus-Response Theory and the Association Theory developed by Thorndike and others. The Gestalt school of psychology which arose as a partial protest to the Associationists has also had a significant impact on educators. Whilst there has been a continual development of learning theory for the past 60 years, there are still major disagreements on outlook amongst the various schools of learning.

Recent work has indicated that human intellectual development can be influenced by external stimuli [Mouly 1971] and this has resulted in more studies within cognitive psychology and the proposition of further models of learning. Of these models, Piaget's has perhaps attracted most attention from science educators, especially in the past two decades, as evidenced by the very large number of research reports and other types of publications in science education literature [Bady 1978; De Carcer et al 1978]. Mallinson [1977], summed it up well when he stated:

> Education is replete with ascendance and descendance of
> Messiahs who capture the fancy of those who teach.
> The twentieth century has had its share; for example
> Thorndike and Connectionism, Dewey and learning by doing,
> and Bloom and his taxonomy of Educational objectives.
> There have been, of course, many others, but
> the current star is Piaget.

American educators did " rediscover " Piaget in the 1960's and his popularity rose in part as "inquiry" and "discovery" oriented science and Mathematics curriculum innovations were promoted with large federal grants [Mulopo 1983].

1.1 Piaget and developmental stages:

While no attempt will be made to provide an exhaustive discussion of Piaget's theory, it may suffice to highlight the salient features of the model in order to establish a premise for the rest of the discussion and the review of the literature; and to provide a theoretical perspective. It is felt by many science educators that Piaget made three major contributions to science education. The first of these [Malinson 1977] is Piaget's proposition that intellectual development involves a process of adaptation through accommodation and assimilation. On receiving new information from his environment, the child assimilates it, thereby upsetting the equilibrium. He then restores the equilibrium by attempting to form a new concept using the disequilibrating information [Driver 1983]. The important implication is that the child plays an active rather than a passive role.

The second involves the properties of logical thought, and Piaget cited four important manipulations to exemplify the idea.

Combinativity --- the ability to add ideas
Identity --- the ability to compare and contrast phenomena
Associativity --- the ability to add numbers in different ways and still come up with identical results.
Reversibility --- the ability to 'retrace a path' in reverse order mentally

The third contribution made by Piaget concerns the development of "propositional thinking" during adolescence. In other words the child's cognitive functioning progresses towards a stage whereby he is able to identify variables associated with a proposition he has made or stated, to combine these propositions and test the possible combinations.

The above ideas led Piaget to identify four main stages through which children's intellectual ability develops. These have been described as follows:

The Sensory-Motor Stage: birth to about one and a half years. At this stage the child acts via basic reflexes and controlled reflexes

The Pre-operational Stage : 18 months to about 7 years. During this stage the child learns mainly on the basis of his perceptions of reality rather than via logical operations. The child is capable of dealing with one item at a time.

The Concrete (or Logical) Operational Stage : 7 to 12 years. During this stage the ability to use logical operations and deal with multivariate phenomena develops.

The Formal Operations Stage: 12 years up to High school years. The learner during this stage is capable of propositional thinking.

The four stages are hierarchically attained, and each stage is necessary for the development of the succeeding stages [Piaget 1967; Duckworth 1964].

Most of the early studies dealing with Piagetian Theory were directed at testing the validity of some of its components. Later investigations concerning the ages assigned to each level of cognitive development have provided evidence that has challenged and in some instances contradicted Piaget's earlier postulates [Chiapetta 1976; Mulopo 1980].

1.1.1 Related research and findings:

Recent investigations have provided overwhelming evidence to the effect that rates at which a particular cognitive stage is attained, vary from person to person in the one culture, from one socio-economic status level to the other, and across cultures [Nordland et al 1974]. Research reviewed indicates that the majority of adolescents function at the Concrete level and not at the formal Operational level. There is an established general feeling, and experts agree, that High school and College teaching often deals with relatively more abstract and therefore difficult concepts and principles. Piagetians feel that these concepts mainly require intellectual abilities at the Formal Operational level [Howe and Rowe, 1982].

Evidence regarding the idea that the majority of High school and College students seem to be operating at the concrete operational level has given impetus to numerous studies aimed at determining how the development from concrete to formal reasoning could be facilitated [Lawson et al 1978]. Other researchers have attempted to formulate principles or guidelines for selecting or appropriately modifying science content and instructional approaches so as to make resulting experiences suit the learner's intellectual abilities, for example Cantu and Herron [1978]. Some of the follow up investigations have focussed on attempts to accelerate the transition from the Concrete to the Formal Operational level amongst science students [Lawson, 1980].

Research on the science of learning has been active at College / University level, in general. There has been considerable concern about the problems that beset students who have just come out of the schools system.

A great number of studies are continually being added to the already rich assortment of science education research related to Piagetian cognitive development theory. Whilst it is difficult to isolate completely developmental level research from other learning studies, one may mention that the special categories receiving current attention are:

(i) developmental level and spatial ability,
(ii) developmental level and science achievement
(iii) developmental level and other student characteristics
(iv) developmental level, intervention techniques and change in student performance

Some researchers have reported significant relationships between the level of cognitive development and student success in science courses or problem solving. Arons [1976] reported on the identification of certain specific factors and procedures designed to assist the attainment of the formal operational level of intellectual development. This particular report concerns university students who are at the concrete or transitional stage. He suggests exploratory activity and question-asking prior to concept formation and model building as a procedure to be adopted; and he proposes that the idea should be introduced first and the name [for the concept] given only afterwards. There is a problem in physics with names cropping up and taking a firm hold before the concept has been assimilated, especially because a lot of them are old names which are used informally in conversational language; for example force, energy, current, resistance etc. Students should also be taught the processes of translating words into symbols and mathematical relationships.

The author also suggests that one reason why undergraduates have never developed specific reasoning capacities must be because their school teachers could not help them; that they probably do not have these capacities themselves. Preconceptions and common sense beliefs about physics phenomena that students bring to the physics courses are identified as a factor in this paper. Conceptions that students hold are an important factor in order to succeed in physics. He also stresses the need to attain 'formal' modes of reasoning, and mathematical skills as being extremely important factors.

Renner and Paske [1977] compare two forms of instruction in college physics which they refer to as concrete instruction and formal instruction. The concrete instruction teaching methodology provided the student with materials and instructions to work with whilst he was learning. In other words the concrete instruction mode was intrinsically laboratory based whilst the formal instruction methodology was lecture based. The methodologies were used on two groups of students at the University of Oklahoma. The authors maintain that there was conclusive evidence that, amongst other things, students experiencing concrete instruction achieve higher scores on examinations dealing with physics content than the others; and that concrete instruction promotes intellectual development at both the concrete and formal levels, whilst formal instruction advances the intellectual development of only those students who have entered the formal operational stage. They then conclude that, since approximately 50% of students entering college courses are concrete operational, concrete operational instruction recommends itself for at least the first two years of university.

Cohen et al [1978] found the Piagetian level of previously experimentally rated students to be only weakly correlated to final course grades achieved by these students; and these findings have invoked some interesting comments, which challenged the validity of this assertion, from Arons [1979] and Lawson [1979]. General cognitive and specific cognitive processes have been listed by Champagne et al [1980] as major factors influencing the learning of classical mechanics. Barnes G and Barnes G B [1980] report on students' scores on Piagetian-type questionnaires before and after taking two semesters of College physics and establish that the pre - and - post test score differences were far from being statistically significant. The question to ask here is whether we may expect that by teaching physics alone to students the developmental level of the students is assured of improvement. Renner et al [1977] suggest this, but there is still some doubt about the validity of that assertion. Is it only some forms of physics instruction that will necessarily improve Piagetian skills of the students?

Maloney [1981 b] gathered data on the Piagetian level of physics students in a large liberal arts university and found that most were at the formal level of development. Maloney D P (1981 a) discusses the validity of certain paper and pencil methods of Piagetian testing and concludes that evidence at this stage suggests that the validity of the test instruments is still in question. The criticism of the work of Cohen [1978] by Arons [1979] and Lawson [1979] in the papers discussed earlier does seem to point to this and challenges the sampling procedures. It does seem that the design of test instruments is still at a developmental stage. So, Piagetian research is still very much alive and developing. Questions are still being debated regarding the influence of testing inside a specific subject matter content area or how the knowledge state of the child influences the result. There are still linguistic and cultural implications to unravel.

Studies reported in 1981 show strong relationships between developmental level and science achievement, but they suggested that age and grade were only weakly related to developmental level and cognitive achievement [Klopfer 1983]. Noted also was that gains in cognitive development were being made through special intervention techniques.

The emphasis on active participation (as opposed to passive reception of knowledge) by the learner embodied in Piagetian theory has made it more relevant to science teaching, and from the 1970's 'inquiry' and 'discovery' approaches to learning began to be held in high esteem. It is evident that the model occupies an appropriate niche in science education today.

1.2.0 Ausubel and the theory of Assimilation :

Studies on the science of learning have not all been strictly along Piagetian lines. Concurrently there has been a much broader approach to the nature of science education and its attendant phenomena. Driver and Easley [1978] have critised the Piagetian position, and insist that since all observation must be theory laden, it is the pupils' notions, which will be important in drawing understanding out of an experimental situation. In addition the work of Ausubel [1968] also emphasised that students have to relate new items of knowledge to pre-existing conceptual structures [Solomon 1987].

There is a growing conviction that the problems of science teaching and learning involve different areas of knowledge, notably:

(i) science itself
(ii) the psychology of learning, and
(iii) the epistemology of science

In the past educational psychologists have been criticised for the low educational relevance of the many examples that they choose to work on. Also, there has been rather little attention paid to the characteristics of the subject matter which is taught to the students. As a result calls have been made for a more careful consideration of not only the scientific content but also the science processes reflected in science education.

Traditionally science is taught in the schools as a set of rules, for usefulness in explaining natural phenomena and as technology to the extent that it may be interpreted by the receiver as prescriptive rather than tentative. For a more adequate representation of scientific knowledge, with teaching at the upper secondary school and college level in mind, the focus should not only be on learning theories but should include the nature and epistemology of science. I have had opportunity several times of interviewing student teachers in their postgraduate year, and less than 10% each time understand science as a process of exploration, of developing explanations, and of testing these explanations. It is generally accepted that the main mode in which scientific concepts are acquired at college level is that of receptive verbal learning (assimilation) of the concepts.

During the 1970's the influence of other cognitive theorists, notably Ausubel, increased. In the debate about the validity and status of the stage theory of Piaget, a different interpretation emerged, on how the different stages may be sequentially and chronologically attained. The new interpretation challenged the idea that there is an age restriction on learning. Instead, it suggested that the age and sequence in which tasks are performed are simply a function of the complexity of the task and the prior exposure or experience of the individual to related concepts.

Ausubel's theory of meaningful learning offered science education a more useful and valid model of learning than the Piagetian stage model [Driver 1983]. Where Piaget's model focusses mainly on content independent logical structures or operations, Ausubel postulated that knowledge is structured as a framework of specific concepts. Ausubel further postulated that the most important factor influencing learning is what the learner already knows [Driver 1983]. He emphasises the role of verbal learning and distinguishes between rote learning and meaningful learning. This theory was further elaborated by Novak [1978. b].

In the framework of the assimilation theory of Ausubel the requirement is that, in our approach to science teaching at the upper secondary and College level a distinction should be made between

(i) knowing - for example the physical world using the tools of science like Physics - and
(ii) reflecting on the activity of knowing

Driver [1983] emphasises this point even more clearly: A fundamental difference can be made in science or any other field of empirical enquiry between two general kinds of activities. On the one hand there is the observation and cataloguing of sense impressions, the experience of the phenomena; on the other there are our attempts as humans to impose some regularity on experience by creating our models or theoretical entities.

> Science is not just a collection of laws, a catalogue of facts, it is a creation of the human mind with its freely invented ideas and concepts. Physical theories try to form a picture of reality and to establish its connections with the wide world of sense impressions (Einstein & Infeld 1938)

The learning of concepts in the receptive mode, for example from a book or an audiotape, is dependent, amongst other things, on the logical meaningfulness of the material which is presented to the student. Learning is also dependent upon the organised representation of knowledge in the memory of the learner, that is, the learner's cognitive structure. We have to accept the conventional wisdom that the formal learning of science at schools and colleges ought to involve not only gaining an acquaintance with the phenomena of the natural world (such a pursuit might be called natural history); it should also involve learning about the theoretical entities which have become accepted within the scientific community; this latter disciplinary knowledge comprising the particular concepts, the relationships amongst them, and their symbolic relationships.

It should be kept in mind, however, that logical structure of the subject matter in a discipline, is not something given and unchanging; rather, it is the result of reorganisation of raw knowledge as it arises within the context of discovery, - a translation of 'private science' into 'public science'. There are usually underlying epistemological assumptions about the nature of scientific knowledge which condition representations of conceptual knowledge. One such assumption is the distinction between two types of knowledge which appear in school science :

(i) knowledge obtained by looking outside ourselves and mastering the world we live in, and
(ii) knowledge that derives from our reflecting on our capacity as "knowers" which is the purpose of "second order subjects" namely the various philosophies.

Accordingly Driver [1983] maintains that students must from an early age, like scientists, engage in both activities and that the products of such endeavours have a significant impact upon the way they interpret instruction in the classroom. A quick review of recent literature shows clearly that research in science education has used the "student as a scientist" metaphor both implicitly and explicitly and raised a number of theoretical and methodological issues emanating from that inquiry.

Until recently the major emphasis in the development of most science curricula had been directed towards the structure of the knowledge to be taught. Now there is evidence of a growing welter of literature and research which indicates that researchers accept that students do possess 'invented ideas' based upon their interpretation of sensory impressions, which influence the ways in which they respond to and understand the disciplinary knowledge as represented in the classroom; a form of personal experience. Evidence for the claim that students have intuitive ideas about natural phenomena abounds in the now extensive journal literature, some of which is summarised in Table 2:

TABLE 2

SELECTED STUDIES ON PUPILS' CONCEPTUAL FRAMEWORKS ABOUT NATURAL PHENOMENA IN THE PHYSICAL SCIENCES

Topic	
Dynamics	Champagne, Klopfer and Anderson 1980 Clement 1982 di Siessa 1981 Mc Closkey 1983 Sjoberg and I 1e 1981 Trowbridge and Mc Dermott 1981 Viennot 1979
Gravity	Gilbert, Watt and Osborne 1982 Gunstone and White 1981 Stead and Osborne 1981
Heat	Anderson 1980 Driver and Russell 1982 Engel 1982 Erickson 1979 Erickson 1980 Strauss 1981b Tiberghien 1980
Light	Guesne 1976 Stead and Osborne 1980
Particulate theory	Novick and Nussbaum 1978, 1981
Density	Hewson 1982 Rowell and Dawson 1983
Electricity	Fredette and Lochhead 1980 Osborne 1981 Russell 1980 Shipstone 1982
Air and air pressure	Engel 1982 Engel and Driver 1982 Sere' 1982

from Driver [1983]

Virtually all this work stems from a "Constructivist Epistemology ", [Driver 1982; Osborne & Wittrock 1983; Pope & Gilbert 1983] in which it is assumed that learners generate meaning from personal experience.

1.3.0 The Constructivist Tradition:

Each student entering a first course in University Physics possesses a system of beliefs and intuitions about physical phenomena derived from extensive personal experience. Experience may arise from the classroom situations and directed activities therein as explained above. It may also be the result of perceptions, interpretations, mental modelling and conclusions arrived at, from direct and indirect observations of natural phenomena, and interactions with the environment. Until quite recently common sense beliefs which are incompatible with established scientific theory were being quickly labelled as 'misconceptions' and dismissed by most scientists. In the traditional classroom situation teachers still pretended that they were just stupid mistakes, incorrect answers, and got on with the job of imparting knowledge as they understood it. Essentially there was very little research done to find out why the students made the mistakes they did. But, as research has shown, students are not easily disabused of common sense beliefs, because their own beliefs are grounded in long personal experience; the "misconceptions" are not arbitrary or trivial mistakes. Indeed, every one of the misconceptions about motion common amongst students today was seriously advocated by leading intellectuals in pre-Newtonian times [Halloun and Hestenes 1985]. Accordingly, common sense beliefs should be treated with genuine respect by instructors.

As indicated earlier, there has been a major upsurge in interest within science education in so called childrens' science [Gilbert 1982]. Of particular interest are:

(i) the associations with natural phenomena and physical environment which children bring with them to science lessons; and
(ii) the impact of lessons on those ideas

1.3.1 Related Research and findings:

Conferences have been organised to discuss and report on findings [Helm and Novak 1983; Duit, Jung & Rhoneck 1984; Int workshop on Res in Science Education La Londe les Maures France 1983]. Some excellent reviews of 'alternative conceptions studies' research have already been produced and appear in the journal literature [Osborne & Witrock 1983; Driver & Erickson 1983; Gilbert & Watts 1983; Champagne Gunstone & Klopfer 1983]. These findings have established beyond doubt the existence of prior concepts, and that these are frequently different from scientists' views; that they are frequently not well known by teachers although children find them sensible and actually use them. The childrens' views can remain uninfluenced or be influenced, sometimes in unanticipated ways, by classroom activities. It would appear that the "Constructivist Epistemology" is supported by all this empirical work [Driver 1982]; that the fundamental assumption that learners actively generate meaning from experience is quite legitimate [Osborne & Wittrock 1983; Pope & Gilbert 1983]. The Constructivist tradition rests on the view that a learner's existing ideas are all important in responding to and making sense of experience by actively constructing meaning.

Experts agree that whilst the origins of the Constructivist tradition date back to the Greeks, one of the major influences on the constructivist tradition in recent times has been the writings of Piaget [Osborne & Wittrock 1983]. Although Piaget is often cited for his work on child development he was a constructivist [Driver 1983] because he considered that

(i) all knowledge is constructed by the individual as he or she interacts with the environment and tries to make sense of it; and
(ii) all knowledge is acquired not by the internalisation of some outside given meaning but by the construction from within, of appropriate representations and interpretations.

In fact Piaget's ideas about assimilation and accommodation fit very comfortably within what is generally accepted as the Constructivist tradition.

One strand of research studies undertaken within the Constructivist perspective follows a Piagetian tradition in attempting to identify generalised 'content independent' forms of thought or operative knowledge [Lawson 1982]. The other strand focusses on the study of the individual's knowledge about specific content domains. This particular review will mainly concentrate on the latter.

1.4.0 Alternative Conceptions Studies in general:

Various approaches have been employed by researchers in an effort to capture some aspects of students' ideas and this diversity of approaches has created a proliferation of terms, techniques and supporting theoretical rationales for describing the cognitive commitments of students. All those who are involved in it agree that this field of research is still at the pre-paradigmatic stage [Gilbert & Watts 1983]; that there are as yet no general agreements on the aims of enquiry, methods to be used, criteria for appraisal of data, the use to be made of the outcomes etc. For any coherence to appear in the field some semantic knots still have to be untied. One of these concerns the epistemological and ontological status of the descriptors used for the outcomes of such studies. They are severally referred to as "misconceptions" eg Helm [1980]; "preconceptions", [Novak 1977]; "alternative conceptions" [Driver & Easley 1978]; "childrens' science " [Gilbert, Osborne & Fensham 1982]; "alternative frameworks" [Mc Clelland 1984] and also by Hewson & Hewson [1981]; "intuitive views " [Preece 1984]; "common sense concepts " by Halloun and Hestenes [1985]; prior concepts and so on.

If one was to judge by the names assigned to them, the conceptual primitives / positions of students are suspected to have many and varied specific origins. They may arise naturally as simplistic naive outlooks and common sense, as children's science, as pre-conceptions, as intuitive ideas, etc before formal learning has taken place; or may even be guided by a commitment to a set of principles outside science itself. With more certainty they may arise as misconceptions, tendencies in interpretation, through the consistent and deliberate activities and actions that are initiated in the formal and informal circumstances of the classroom situation.

It is now well established that many incorrect conceptions are also picked up by students from textbooks and from teachers, [Fredette and Lochhead 1980; Osborne and Gilbert 1980; Lawson 1979/83]. Students have reading difficulties and textbooks present serious problems of comprehension to most of them. There is a need to adapt further the nature of scientific writing and to make the language simpler and easier to understand; ie to reduce the readability level of science textbooks. Many of the words used in science are also used in everyday language. Students have to handle the same scientific words (force, weight, field, mass, potential, energy etc;) but with different meanings, either the scientific or the common use meaning. Very often there is no rigid correlation between these two. Johnstone [1978], has shown that the words which cause most trouble are not so much those which are purely technical but those which are in normal English usage, and which have a rather specific meaning in science. Words like 'fuse' in the place of 'melts'; an appliance 'using' current as it is operational; 'energy', 'current' etc;. These secular meanings of words are embedded in the long term memory and are inexorably linked to the students' constructions of how and why things behave as they do, and affect the formation of appropriate concepts.

It seems to me that a more appropriate and all embracing descriptor for all these would be "alternative conceptions". The latter term unlike "misconceptions" does not commit itself to the 'correctness' or not of these frames, neither does it align itself in meaning to the specific origins of the particular student conceptions. Another word that could be used for them is "inappropriate conceptions". The only overriding factor about these conceptions is that although they may have seemed satisfactory in the student's mind as simple order theories initially, they turn out to be inappropriate and are incompatible with those acceptable to the majority of the community of practising scientists.

It would not be possible in a limited space to catalogue all the findings and implications of this research program, as there is already an extensive amount of work done. Excellent reviews are already available in the journal literature [Driver & Erickson 1983; Osborne & Wittrock 1983; Gilbert & Watts 1983]. Here follows but only a brief summary of the ground that has been covered:

"Alternative conceptions" studies have spanned the whole spectrum of general physics, and covered mainly mechanics, heat, light, sound, electricity and parts of modern physics. The results have been very significant and to some extent startling. The outcomes of many studies of force have concerned the strong association of force with motion, its interchangeability with the words momentum and energy, and its separation from the concept of weight. Findings indicate that students understand that when an object does not receive a constant force then the force that caused the motion initially is used up during the movement [Viennot 1985; Halloun and Hestenes 1985].

Traditional teaching styles do not encourage students to reason critically about physical phenomena, and fail to address any thoughts that they may have about the phenomena being discussed. Some teachers let down the students by being unable to reason effectively about the things they teach and merely passing on 'the information' from books. This can be blamed for the incidence of incorrect conceptions in students [Arons

1976]. Helm's work [1978,1980], which attracted popular attention, shows that not only do students 'fail' conceptual mechanics, but so do their teachers.

Other traditional areas of physics covered by this research are GRAVITY [Watts, & Zylberstein 1981; Watts, 1982 ; Moorcroft,1983]; ENERGY [Duit 1984; Richmond 1982; Warren 1982,1983], where some students find it difficult to imagine any inanimate object as having energy at all, especially whilst at the same time being stationary. Amongst science educators also, there has been a controversy recently over the 'transformation' framework of energy, where energy is viewed as travelling through machines and wires and changing appearance at different points [Warren 1983; Falk, G et al 1983].

Alternative conceptions research has been worthwhile and reasonably extensive in most of the other fields of physics; for example sound , optics and electricity. Some ideas children hold on Heat have been investigated [Driver 1983]. The investigations done in the section on light and particulate nature of light have revealed incorrect conceptions in those areas of the subject matter [Gilbert & Watts 1983].

Alternative conception studies in electricity have been of particular interest; the field has been very active at all levels of school, and some fundamental and deeprooted incorrect conceptions have been uncovered [Duit, Jung and Rhonech 1984; Johnstone & Mughol 1978; Johsua 1984; Fredette & Lochhead 1980].

The overall picture indicates that research has been quite intense for all school and pre-school age levels. The kinds of enquiry and findings have proved of increasing interest to research workers and science teachers. Indeed the evidence of 'alternative interpretations' has been so prolific and diverse as to make it imperative to look again at the need for some new objectives for science education.

The research has also shown that mature students, including university students, already have preconceptual commitments, [some of which are incorrect], in the sections outlined above. This may be expected as mature students ought to have experientially verified principles concerning sound and auditory phenomena, light vision and colour, temperature, magnetic and electrical phenomena.

1.4.1 Studies related to College / University Students:

Research on 'alternate frameworks' of students at college and university level has covered some ground [Hewson 1985; Peters 1982; Clement 1982; Lythcott 1985; McCubbin 1984; Helm 1978; Fredette and Lochhead 1980 etc]. Although such research only got off the ground in recent years, significant implications for instruction are already apparent and profound.

Most of the research on 'alternative conceptions'; 'alternative frameworks' etc; in university physics has been in the area of mechanics. A large proportion of research workers have tested in this area because mechanics is a more fundamental section of physics. They have felt quite legitimately that all students probably begin the formal study of mechanics at university with an historically 'verified' set of principles that allow them to predict the motion of objects, because such practical principles are necessary for coping with moving objects in everyday life.

The investigation by Peters [1982] established that even honors students in an introductory physics course at the University of Washington exhibit the same kinds of 'misconceptions' as do the other students in the standard courses, in most sections of physics including Kinematics, Dynamics and, Electricity and Magnetism.

When one searches for the sources of difficulty that students encounter in physics, one can identify many contributing factors, such as abstractness of the material, degree of logical precision required in problem solving, sophistication in the type of reasoning required, and the mathematical skills required . Thus it is evident that physics at the College level offers a fertile field for research in 'alternative conceptions' studies. Peters highlights the presence in physics of inherently difficult "conceptual primitives" including

(i) key concepts such as mass, acceleration, momentum, charge, energy, potential difference
(ii) fundamental principles and models such as Newton's laws, conservation laws ,the atomic model, electronic flow models for circuits etc

His conclusions from this research are that difficulties with conceptual primitives appear to originate in intuitive preconceptions that the student develops on his own before entering university physics courses. This paper discusses a particularly strong preconception in the area of force and motion; which makes an understanding of F=ma even more difficult because it conflicts with the beginners intuitive preconcept about motion:

the "continuing motion implies the presence of a continuing force in the same direction" preconception.

Peters [1982] presents empirical evidence that many beginners apply this point of view to various simple mechanics problems. This particular misconception appears to be still present in many students even after they have completed a course in mechanics. Related studies by Viennot [1979]; Northfield J & Gunstone, R [1983]; Trowbridge [1980], and many other researchers also support these findings. My own experience has been that about 70% of all the students entering the first year university course in physics consider that a body which is moving vertically upwards (after being thrown up by hand) has an upward force acting on it even if it is no longer in contact with the hand.

"Why is it going up if there is no upward force
acting on it ?" S.1

"The force of the hand still acts on the body, but
it becomes weaker (dissipated by the motion) until
at the top the weight (as a force acting downwards)
overcomes the force of the hand in the body
and then the body will move downwards" S.2

I have monitored this with generations of first years for more than ten years and an average of 70% continues to manifest this conceptual position and consequently, are unable to relate to the essence of Newton's Second law for accelerated motion $F = ma$; that the acceleration must be in the same direction as the resultant force vector acting on a system. Using similar arguments a puck that is sliding along (after being thrown) on rough surface is considered to have acting on it not only the friction force (backward) but also a forward force for as long as the particle is in motion.

Clement [1982] had comparable findings in his research. He argues that since friction is not recognised as a force by the beginning student, he may believe that continuing motion then implies the presence of a continuing 'unbalanced' force in the same direction as the motion.

Trowbridge & McDermott (1980/81) investigated the understanding of the concept of acceleration in one dimension. This latter report indicates that introductory physics students frequently lack even a qualitative understanding of the concept as the ratio dv/dt and that the conceptual difficulties encountered by students appear to be very persistent. Implications for instruction are then discussed.

Many university first year students that I have come across think that any object which is in motion must be accelerating; those that maintain a constant velocity in time are accelerating with a constant velocity (acceleration is constant), whereas the others accelerate with an increasing velocity (=increasing acceleration). In this frame the regularity of the change of velocity does not get into the picture at all. If an object moves at a very high 'uniform' velocity (at a 'fast' speed) then its acceleration is very high. The conceptualisation of the 'acceleration' concept is very shallow and one does not know whether this is a problem of inability to relate to rates, and consequently a difficulty with formal reasoning.

Champagne, Klopfer and Anderson [1980] list the incorrect understanding of conceptions before formal tuition in them, as one of the factors that lead to difficulties in the learning of classical mechanics. More recently Halloun and Hestenes [1985] have produced two papers in which they present the results of an investigation of what they call "common sense " concepts of students about motion; and the results establish the existence of misconceptions which they argue are

(i) neither arbitrary nor trivial, are very stable and that conventional physics instruction does very little to change them.
(ii) generally incompatible with Newtonian theory.

Most of these alternative conceptions are highlighted in the papers discussed earlier. The other thesis in this paper is that it is inappropriate to think of student belief systems, although labelled as such by many, as Aristotelian; that the Aristotelian system was far more elaborate and logically consistent; that student belief systems are closer to the Medieval Impetus Theory.

Whilst Lythcott [1985] reinforces further that students do hold ideas about force and motion which suggest that in the absence of force things are necessarily at rest, she insists that these student believe systems are not like those of Aristotle, but are probably fragmented systems of related (or not) naive student conceptions. This is in line with Halloun et al [1985]. Lythcott also contends that the Aristotelian theory was far more elaborate, comprehensive and consistent; which cannot be said of the student theories. Further, the main thrust of this paper is on the whole problem of nomenclature in science and how this influences the understanding of the 'named' concept; and how in general "naming" in the sense of identifying may impede and restrict the development of science.

The point that Lythcott makes here is that the matter of nomenclature is not a trivial one in any theory. She issues a warning on how names for new concepts may enhance or prejudice the growth of science around that particular concept. The example of Faraday is given, who in his efforts in the development of an appropriate electrochemical theory, considered it very important when putting together his theory (much of which was debatable at the time) to give 'names for concepts' that would not enhance a particular theory and prejudice others. Words for concepts can contract and confine (limit) the habitual view of those engaged in the pursuit of the associated conceptual frameworks. Labelling in science is not an activity to be taken lightly. At the beginning of this study I also had found that the words used for certain concepts influenced the understanding of these by my students.

Viennot's [1985] approach to alternative conceptions research is that some of these may be classified as 'tendencies to interpretation' and sometimes as 'spontaneous reasoning' of students. The example given here is that students at secondary school and university level often answer as if there is a direct relationship, more or less linear, between velocity and force, or as if motion implies an 'unbalanced' force in the same direction. She also argues that students in their spontaneous reasoning are usually not conscious that the notion of "force acting on a body" sometimes indifferently refers (in their minds) to the concepts "force", "impetus", "energy", "momentum" etc; in that body.

Viennot also comments on the way we tend to interpret students' intuitive responses, and warns against accepting all common mistakes and interpreting them in terms of 'intuitive reasoning ' or 'misconceptions'. So it is important to make it as clear as possible how we pass from systematic and resistant students' mistakes to assumed 'misconceptions' and 'alternative reasoning'. There are many situations in which students are just individuals without any clear beliefs or expectations. In such situations we may think in terms of both verbal and physical analogies as being the sources of error [Driver & Erickson 1983]. Language and metaphor also play a significant role.

There have been other studies at university level which have tended to link the lack of logical reasoning with students' alternative conceptions [Arons 1982]; or with the lack of adequate mathematical skills [Hudson and McIntyre 1977 ; Champagne et al 1980; Hudson and Rottman 1980; Griffith 1985] or with their general level of cognitive development [Champagne et al 1980]. In my opinion the link between the cognitive development level of students and their ability to assimilate scientific concepts is an extremely important one and could lead to further insights in research on alternative conceptions. One can only make preliminary comments about this at this stage: It would seem that the more mature student has less difficulties in correlating schemes of thought. Again this could be related to the student having more frequently been exposed to the associated concepts in the past.

Champagne and Klopfer [1983] document at length some interesting explanations of alternative conceptions including their character and influence on instructional events and also the reconciliation of these with scientific theories.

The above survey of incorrect conceptions in mechanics has been included because I believe these conceptions are related to how students interpret electric circuit phenomena like the flow of energy, the flow of electric curren (=flow of electrons) and especially their treatment of electromotive force as a force. Students, it seems, try to use reasoning from mechanics when they explain the movement of electrons in a d c circuit. As it turns out some of this reasoning is not correct even in terms of mechanics.

I would like to point out here the role of words / names for concepts as being very important, especially in relation to words like energy, force, charge, current, emf, in the sense that most if not all of these have come into physics with biases in their meanings arising from use in common language. This will be discussed later and at length.

Some of the latter research has addressed the issues of how best to accommodate the inappropriate conceptions that have been established. In one of their two papers Halloun and Hestenes [1985] discuss the effectiveness of an instrument which they have designed and which could be actually used as a diagnostic test for identifying and classifying specific incorrect conceptions.

Hewson and Hewson [1981] developed a concept teaching technique that emphasised the importance and use of existing knowledge in influencing subsequent achievement. Intervention techniques have been used also by Champagne et al [1981] with some success. Other possible models of intervention are reviewed by Gilbert and Watts [1983]. Hewson [1985] discusses the effectiveness of an instrument which uses the conceptual change strategy to correct the misconceptions. The conceptual change strategy relies on finding out initial knowledge, including inappropriate conceptions, which students possess before instruction and attempts, using the information at hand, to correct these conceptions by introducing acceptable notions of concepts. Osborne and Wittrock [1983] use the Generative Learning Model as a basis for explaining cognitive processes.

1.5 Studies related to Alternative Conceptions in Electricity:

The field of 'alternative conceptions' research in electricity has been rich, particularly in the past five years, and a considerable amount of work has been done on it in many parts of the world. See the papers which are listed in the table below.

Selected studies on student alternative conceptions in Electricity

Topic	Author	
Identification and analysis of Student conceptions using various techniques:	Aarons	1982
	Duit and Jung	1984
	Cohen et al	1983
	Feher, E	1983
	Fredette & Lochhead	1980
	Johsua	1984
	Iona, M	1979
	Osborne, R et al	1983
	Rhoneck, C V	1981
	Riley, M S et al	1981
	Shipstone, D M	1984
	Solomon, J	1984
Instructional and other intervention strategies to resolve students conceptual problems	Cosgrove et al	1984
	Evans,	1978
	Hartel, H	1984
	Fredette, N H	1981
	Karrquist,	1984
	Osborne, R J	1984
	Psillos et al	1987
	Rhoneck, C V	1984
	Steinberg, M	1983
	Closset, J L	1984
	Duit, R and Jung, W	1984
	Mc Dermott & van Zee, Shipstone, Hartel, Jung, Closset, etc in Duit & Jung	1984
Clarification and Reinforcement of certain aspects of specific concepts in d c electricity theory in general	Falk et al	1983
	Heald, M A	1984
	Iona, M	1984
	Johnstone & Mughol	1978
	Ogborn and Wong	1984
	Osborn, S J	
	Peters, P C	1984
	Preece, P F W	1976
	Roberts, D	1983
	Rose-Innes	1985

A look at the proceedings of the "Conference concerning Students' Representation of Physics and Chemistry Knowledge" Ludwig'sburg Germany Sept 1981, and the International Seminar on Misconceptions in Physics and Mathematics (Cornell University, June,1983) shows that the section on electricity alternative conceptions received considerable attention. In September 1984 there was the very significant "International Workshop on Aspects of the Understanding of Electricity" in Germany in which R Duit and W Jung attempted to coordinate all international research done on the representation of students' knowledge in Electricity and its uses for the improvement of teaching.

Helm [1978 and 1980] investigated in general some misconceptions amongst South African university physics students, high school pupils and teachers of physical science and discovered some deeprooted misconceptions in the section on electricity. Analysis here indicates that students are confused about emf and potential difference, and treat electric current as being equivalent to energy.

The work by Evans [1978] is an attempt at resolving the conceptual difficulties of students in electricity. He outlines a strategy of introducing high school and college students to direct current electricity that is based on providing the practical experiences with electricity circuits that the students need, before they could be expected to indulge in any meaningful conceptualisation of the related ideas and concepts. This strategy recognises that the traditional treatment of electricity at high school, as well as at university, is highly 'formal and abstract'; and that no student who has not had experience with simple electricity circuits may be expected to understand their operation in terms of "abstractions like charge, force per unit charge, and potential energy".

The author proposes here an alternative programme which is based on hands on experience, practical observations and interactions with circuit phenomena. This would lead to the student discovering for himself, one at a time 'the need for abstractions like resistance, current, potential difference' etc;. The argument here is that the student needs to master the qualitative model before he may be expected to reduce quality to quantity.

The practical approach has great merit but the one criticism against it, especially the one proposed by Evans [1978], is that it is long and tedious. His method, I think, would lead to confusion in so far as the strange units and concept names [shoves and glows etc;] he has used in this particular article. One would rather be advised to stick to the concept names which are used standardly in textbooks. Also, my experience with using batteries and especially bulbs produced commercially is that they are not accurately standardised; and sometimes similar bulbs will not show equal brightness. This can lead to incorrect conclusions by students if their adventures in experiments are not closely monitored.

Fredette, N and Lochhead, J [1980] investigated students' conceptions of simple electric circuits using engineering majors enrolled in first year university courses. They report that both clinical interviews and group survey data indicated that many students enter university level courses without a clear understanding of the 'passing through' process of current and rather think of current as flowing to a lamp and NOT through it. They establish that students' thinking is basically constructed (anchored) on the sound and natural assumption that the lamp glows only because the battery has supplied energy to it. This unfortunately leads to an incorrect conclusion: The electricity (=current and not energy) goes to the lamp to cause it to light, and not through it.

My interpretation is that the problem here is caused by the fundamental lack of distinction in life world situations between electricity the energy and electricity the current; and an inadequately elaborated model for the 'supply' of the energy to the lamp in the circuit. More clearly this is caused by the failure of instruction to present the electric circuit properly as an energy system. It is otherwise not without logic to hypothesise that if the battery is the source of electricity (energy) then the lamp glows because electricity (=energy=current?) has been supplied to it by the battery. By the nature of this argument there is no need for the 'pass through' requirement for the electricity (=current) since the electricity (=energy) is going to the lamp. I do believe that the manner in which teachers talk about happenings in an electrical circuit influences the conceptualisation of ideas like 'electrical' energy, current etc; and encourages the formation of incorrect conceptions. This will be discussed in more elaborate detail later.

Fredette and Lochhead emphasise the importance of hands on experience, active involvement by the student with simple electric circuits over a considerable time, in order to help resolve these conceptual conflicts. This approach was also suggested by Evans [1978] as discussed earlier. Fredette [1981] claimed that students' misconceptions were due to the fact that the standard physics instructional models do not build upon existing knowledge structures. The electricity theory is largely based on its own models and although there is mention of movement, (potential) energy etc the models are not compared strictly with those from mechanics.

Riley and others [1981] report the results of a research project designed to investigate the acquisition of problem solving skills in basic electricity. One of the goals of the research was to identify the kinds of representations that novices can acquire more easily and that will eventually lead to a more skilled performance, in problem solving. One of their findings was that the subjects frequently attempted to use the flow analogy (either electron or water flow) to reason in a time dependent way about electric current. This reasoning, coupled with the subjects' understanding of voltage and current, leads to the following incorrect inferences:

(i) if voltage drops at each successive resistor, and voltage is what pushes current, then current 'slows down' as it moves through the circuit.
(ii) Resistance is like friction that impedes current flow; therefore current becomes increasingly slow (less) as it passes through each successive resistor.

Both of these inferences violate the global constraint that current is the same everywhere in the series circuit.

Although electrical potential (energy) and electrical potential (energy) difference (= p.d) are used extensively in the theory, my observation is that these difficult concepts are not ever developed adequately during formal instruction. Instead even the word "energy" is habitually left out in potential (energy) difference by both teachers and students. Notably from the last two papers the word "voltage" is overused and in general tends to replace p.d almost completely in the jargon. The word in itself is not self explanatory and tends to lead to confusion between emf and p.d. In some books the word *voltage* is used to mean even potential (energy) at a point in a circuit.

Also, Riley et al found that the subjects relied on solution strategies that were typically mechanically-guided by local features of the problem, retrieving isolated principles and formulas, and using primarily quantitative information to guide the solution procedure. In the latter part, Riley et al discuss the development and use of a written test item to correct alternative concepts, which they have used with some limited success.

The work by Rhoneck [1981] touches on a very important aspect of alternative conceptions studies, the semantic use of words and the relationship between this and the underlying ideas as used in the theory in physics. Most words in electricity theory have life world meanings which unfortunately tend to take over; for example current and even energy. Some words like electromotive 'force' tend to mislead in meaning because emf is not a force. It would help to facilitate the conceptualisation of these concepts and their equilibration if the concept names were more characterist in meaning.

Arons [1982] proposed that most students need to be helped with phenomenological reasoning when elementary resistive direct current circuit theory is initially introduced. He argues that conventional text presentations, problems and tests etc used do not do this, but tend to channel them into exercises with the use of formulas for series - parallel combinations of resistors or into obtaining circuit equations by application of Kirchhoff's laws; but do not usually evoke reasoning about what is happening in the various parts of a simple circuit. Again the method suggested in this paper in order to improve phenomenological reasoning of students in electric circuit theory invokes active participation in practical work by the students.

Hartel [1982] suggests that, using a new scientific approach, the electric circuit should be taught as a system, where the interdependence of all the quantities involved, current, 'voltage', resistance, etc, is introduced gradually and systematically. He criticises the strong dominance of what he calles the 'measurement principle' in the traditional teaching approach, and points out that the equation V=IR, as it stands and is used, does not really tell us much about how the electrical system works, and is no way of introducing the physics of the electrical circuit. Traditionally students are introduced to simple circuit theory basically by way of the use of the formula V=IR and problems which require almost exclusively the calculations of I, R without an intelligent understanding of the electric circuit as an energy system. As a consequence of this, the students expect the quantities I, R and V to change according to the equation V=IR rather than the circumstances of the circuit. I consider this a very important break-through in teaching and very much agree with it. Textbook writers would do well to take heed and not use the V=IR approach because it does not lead automatically to the understanding of what is really happening in an electric circuit.

College students after a standard "college electricity course" still harbour the idea that current is used up when it 'flows' through a light bulb; the students do not 'conserve' current within circuits [Gilbert and Watts 1983]. In yet another model a current flows from both poles of a battery and meets inside the bulb producing light [Driver 1983].

Cohen et al [1983] administered a test to identify inappropriate conceptions to students in Israel and to their teachers. They found that students generally consider current to be the primary concept and potential difference to be a consequence of current flow and not its cause. They also found the students are unable to use V=IR correctly and generally have a problem in dealing with a simultaneous change of variables, for example the change of V and I across the same resistor at the same time. The students expect the quantities I, R and V to change according to the equation V=IR rather than the circumstances of the circuit.

In much of this framework identified by Cohen et al the students consider the battery to be the source of current and not necessarily that of energy. This is based on the sensible argument that there will be a current in a closed circuit if there is a source, the battery. The current is considered to be the prime concept and the voltage secondary. A simple battery is considered to be a current source and not a source of energy. Voltage remains an abstract concept to which students relate only by using V = I R or experimentally through reading a voltmeter.

Joshua [1984] investigated students' interpretation of simple electrical diagrams and made the following conclusion:

(i) The diagrams are interpreted mainly as representations of a 'system of pipes' through which the passage of current (as a fluid) can take place. The notion of potential or potential difference is rarely introduced.

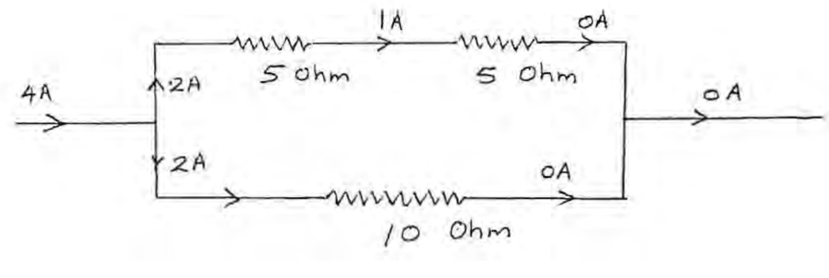
(ii) There is a distinct 'topological effect' discernable in the interpretation of diagrams. What, from a physics view point, are identical representations, are interpreted as different, and vice versa.

(iii) In situations where a circuit element (resistor) is short circuited, the students appear to invoke a notion of 'usefulness' in relation to it, and will 'allow current' through the resistor.

The study by Shipstone [1984] examines the models of 'current flow' which students use, when dealing with circuits, where resistors are either in series or in parallel. He establishes the existence of the misconception of "sequence model" of current flow similar to that referred to as the time-dependent model of current flow by Riley et al [1981]. In this model current flows in one direction around a circuit becoming gradually weakened as it goes, so that the later circuit components receive less current. Lamps which are furthest will be least bright. Fredette [1981] identifies a similar form of reasoning with first year students university engineering students. The other inappropriate models for current flow highlighted by Shipstone are:

(i) Current leaves at both ends of the battery and is used up within the circuit elements
(ii) Current is shared between the circuit components in a circuit. Here too the current is not conserved.

To my thinking the incorrect conception in (ii) above is the idea that the electric current, misinterpreted to be total energy originating from the battery (and flowing out of there) must be shared. The current is understood to set out from the battery to each of the parts of the circuit where it is consumed. It is otherwise not conserved.



Psillos et al [1988] have identified this incorrect conception amongst Greek children and warn that it is important to isolate it early as a factor in pupils; they are otherwise able to use it 'successfully' to explain the values of current in the components of a circuit without conserving current.

Shipstone also discusses the implications for teaching in view of the models for current. He established that most explanations of electric circuit phenomena given by students were in terms of current, electricity, power etc; hardly ever in terms of potential energy, p.d or even emf. These findings compare with those of Cohen et al [1983]. They illustrate quite clearly that the ideas of the electric circuit are not presented systematically, and in a comprehensive manner, during instruction; and also that the related concepts are very poorly conceptualised by students. These concepts of emf, p d and potential, I believe, are the more fundamental ones to the electric circuit as an energy system.

Solomon [1985] tested pupils before formal instruction in electricity, and showed that children at secondary school already have vague pre-conceptions about the nature of electricity guided by common sense knowledge and folklore. These definite pre-conceptions precede and influence school learning and are hard to get rid of; they cannot just be wished away by teachers. The current models isolated were similar to those identified by Fredette, Shipstone and others discussed earlier, namely that

(i) only one wire is needed to bring current to the lamp
(ii) both 'positive' and 'negative' current flows from opposite poles of the battery
(iii) current flows around the circuit but it is partially used up by the lamp or bulb, so that less flows in the remainder of the circuit

This paper also highlights the students' dilemma of not being able distinguish between electrical energy (=electricity in life world situations) and electric current (also =electricity in the life world situations) which they treat as meaning the same thing. In the common sense way, we may not dispute the flow of electricity (energy?) from the generator (battery) to the appliance where it comes off as heat, light etc . We have to take care not to present electric current as 'something' that flows in this sense.

Solomon also makes an interesting and important point that: students as a rule do not construct personal knowledge of a scientific kind as much as they extend a familiar life world way of thinking which requires neither abstract thinking nor consistency. This is the thinking of everyday social exchanges and not that of formal science. In an earlier paper, Solomon [1984], cautions that in teaching some emphasis should be placed on the difference between life world meanings and physics definitions, in order to encourage the all important faculty of discrimination between life world and scientific knowledge domains, and to reinforce scientific meanings. The point to emphasise here is that whether the old knowledge is structured [scientifically] or not in the student's mind, is not the only determining factor. In addition we have to take note of the possibility that the student, even if subconsciously, may use life-world concept meanings and knowledge systems to interpret and model the taught scientific concepts and conceptual models; to equilibrate new concepts and to structure new knowledge; and in that sense these become part of his scientific knowledge. In the constructivist tradition his life-world knowledge is important knowledge, and it should constitute the starting point of his learning [Fredette 1980]. As he learns he will remodel it if and when he is not satisfied with it.

The work cited above and other related papers have established beyond doubt the existence of inappropriate conceptions in an alarmingly large proportion of the student population. In the past five years several attempts have been made to address this problem. Some researchers have attributed the problems to how electricity theory is formally presented initially, and have criticised the traditional teaching methods used in the schools and university.

From the alternative conceptions work discussed above it does seem that the inappropriate conceptions that students have in the theory of simple electric circuits are largely influenced by two factors:

(i) life world outlooks, life world experiences of electricity which students acquire from outside the classroom situation eg: the meanings of words, concept names where these overlap with meanings from everyday life, media images etc .

(ii) the traditional method in which the electricity theory is initially presented through conventional classroom practices and textbooks etc .

It appears that the primary motivation for the investigations listed above was the concern about the incorrect representation of knowledge in a field which already occupies a very large part of what is taught in the secondary schools and universities all over the world. Electricity is already considered to be one of the basic areas of physics at the schools level, and at the university. Unfortunately because it occupies a very significant part of people's daily lives, many incorrect conceptions from that scenario have been affecting formal scientific knowledge of it. It does appear that something must be done to improve its teaching at all levels of learning.

The empirical investigations listed above were carried out largely within the Alternative Framework movement, and have revealed several learning difficulties in the domain of elementary circuits. Many of these are related to the flow of energy in the electric circuit and power. The "use" of electricity, whether as energy or as current (or 'something' else) seems to be a predominant inappropriate conception. These issues seem to be greatly affected by the kinds of knowledge brought in from secular life situations, and are also influenced by how the concepts are presented in formal situations in the schools. Incorrect conceptions have been revealed even in the case of introductory physics at the university level. Quite often these students appear to have inappropriate representations of the structure of simple and branched circuits, as well as false ideas about the flow of current. The students have difficulties with how energy is transfered in an electric circuit. and are still affected by world life outlooks.

In this country the work by Helm [1980] has indicated similar trends with the rest of the world, and he has made some recommendations on teaching of potential difference, for example. Recently some groups at the Universities of Cape Town and at the Witwatersrand have shown some interest in studying students' alternative conceptions. It seemed to me important to do comparable work in South Africa using the Constructivist approach. The investigative techniques of the constructivist approach have been relatively successful elsewhere in uncovering students' inappropriate conceptions as documented in this chapter. The assumption was that our students might have backgrounds that have some similarities to the students elsewhere in the world. I could also document any significant variations or differences if these were apparent.

I was sure that most of these incorrect conceptions will be manifested by the students that I have tested; perhaps other alternative conceptions would be uncovered as well. One of the projections of this study was to gain insights into why the students think the way that they do, why they hold onto the alternative conceptions.

CHAPTER TWO :

PRELIMINARY METHODS AND RESULTS

2.0 HISTORICAL BACKGROUND:

I have already indicated in the introduction that this particular investigation was initiated against a background of the problems and conceptual difficulties of first year students entering university physics courses. A relatively large proportion of these difficulties is the direct consequence of their schooling in ways which are easy to determine and which can be corrected. I have indicated some of these in the earlier chapter, A major part of these problems has to do with the human and other resources which have been invested into the structures of the educational system.

(i) There is a deplorable shortage of qualified teachers in the Black educational system, In reply to a question during the 1988 parliamentary session the minister in charge of the Department of Education and Training indicated that

"about half of the 49 504 teachers employed in Black schools had passed matric, but only three percent were university graduates .. " E P Herald June 30, 1988

(ii) The physical facilities in the form of space and laboratories leave much to be desired.

(iii) It is now generally acknowledged that many incorrect conceptions are picked up from school textbooks and that there is scope to improve especially the style in which textbooks are written.

Generally the crop of students which we get from the schools does not perform well in the natural sciences even at the school level. Evidence of this is the average to below average marks which students achieve /attain in the national examinations at the end of their school career, at standard 10. Following hereafter is a table that gives an idea of how black scholars perform in the national school leaving examinations, when compared with other groups.:

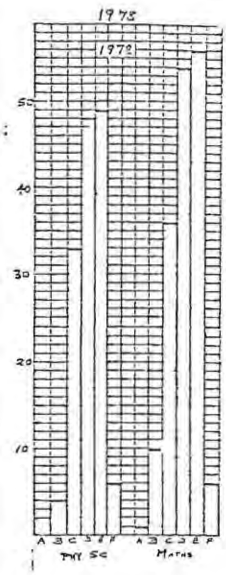
Table : Symbol Distribution In Physical Science HG 1983

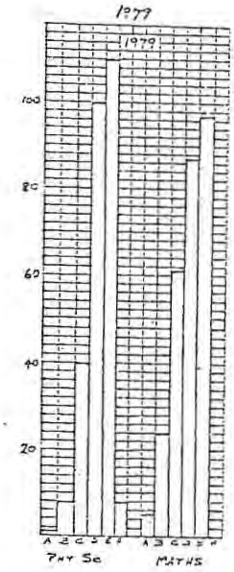
Key: A:80%-100%; B:70%-79%; C:60%-69%; D:50%-59% E:40%-50%
F:34%-39%; FF:30%-33%; G;25%-29%; GG:20%-24% H:0%-19%

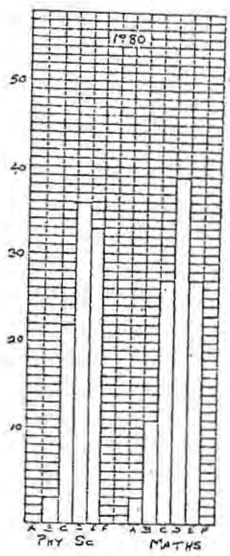
No. of Candidates	PASS					FAIL				
	A	B	C	D	E	F	FF	G	GG	H
Black - 11379 -	0,1	0,1	0,6	2.8	8,6	12,8	8,1	18,1	23,4	25.5
Coloured - 1158 -	1,3	4,1	1,7	18,0	22,9	14,1	7.0	8.0	6,4	6,6
White[Cape] - 3398 -	5,7	11.8	19,0	24.0	21,7	9,6	2,7	2,7	2,0	0,9

*From Mehl and Lochhead
The South African Pariah: Pilot or Pilate [1987]

In the diagram below is a table of the matriculation results of the students who entered our first year physics courses in the years 1978, 1979, and 1980. Close scrutiny of the table indicates that the popular symbols are the low symbols of D's and E's (40%).







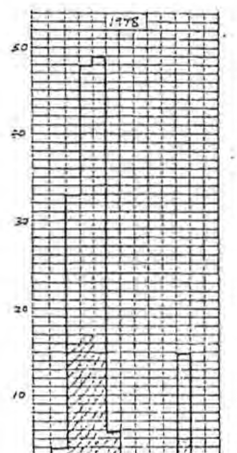
These tables also show that the students generally do as well, if not better, in the mathematics when compared with the Physical science. In order to be admitted to the faculty of science (B Sc including physics 1), students must, amongst other considerations, at least have a pass mark in mathematics (symbol F). This has of course changed in the more recent years to an E standard grade symbol. There is still no requirement that students must have a standard 10 pass in physical science at all, although this may be a general recommendation. This accounts for the larger number of mathematics candidates when compared with the physical science candidates.

2.1 Preliminary Investigations:

In order to confirm my suspicions and to justify this investigation, I did some preliminary analysis of the type of student that is generally accepted for the first year physics courses. For this a questionnaire was drawn up to assess background (school and social), attitudes, and prior knowledge of the students, on the assumption that these would normally affect their learning. This diagnostic test was administered in 1979 [n=330], and in 1980 [n=218]. The results that emerge from the analysis indicate, as would be expected, that the students are indeed handicapped by their background, with factors ranging from understimulating rural home backgrounds and insupportive crowded home conditions in the cities, to inadequate schooling facilities.

Of those tested in 1980, [n=218], 65,6% submitted that they do not have electricity in their homes and only 41,6% of the schools they came from had electricity, even for lighting. This would normally make it difficult to relate to electricity concepts in any meaningful way. Although they enjoyed studying physics at university (75,4%) (half way through the course), they studied it mainly because, directly or indirectly, it offers good employment and salary opportunities (67%). Only a very small proportion thought that they had done enough practical work at the school level (11,9%), and most of this was done by the teacher. There was generally a shortage of adequately qualified teachers. There were also other aspects which were significant to a perhaps lesser extent, which I will not take issue with here.

The fact of the matter is that first year students as a rule do not perform well at the end of school year national examinations. The graph shown below gives some idea of the pass rate for the Physics 1 Ancillary course in the year 1978. The pass rate was not more than 38%. The total number of students who wrote was 158.



Midway through the course in 1979 [n=330], and 1980 [n=218] I administered a questionnaire, in which the students were asked to list in order of priority the five most important reasons for lack of achievement, interest and source of their difficulties in the physics course they were doing at the university.

Below is a list of the responses and an analysis of it.

1.	Inadequate preparation from high school	50,2%
2.	Too many things have to be believed in physics or accepted without really understanding them	49.3%
3.	Too much formulae, more applications needed to relate to reality	40,8%
4.	Too much to cover in a short time	37,0%
5.	Have not adjusted to University life as yet	34,1%
6.	Too mathematical,not enough physical understanding	14,7%
7.	Unable to concentrate on the aspects that I enjoy	13,7%
8.	Lectures were/are poor	5,2%
9.	Physics (or physical science) is just not the subject that interests you	4,7%

From the background data given, and further discussions I had with the subjects, it becomes clear to me that first year students have a difficulty with the understanding of physics concepts and would rather learn them by rote. My impression is that they do not see any unity in the subject or any interrelationship between the concepts they learn and fundamental behaviour of natural phenomena. They tend to go for definitions, thumb rules, and the set of rigid procedures or rules or algorithms which have been "narrated" to them by their teachers. In consultations with them, I have found some students to have problems with basic concepts, especially in mechanics but also in other sections; concepts like work and energy, velocity and acceleration, concepts of motion in general and of force. They are bothered by statements of the conservation principle and tend to take conservation to mean reluctance to part with or to 'exchange' (energy) to another form. They have difficulty with the kinds of reasoning that scientists use regularly. Generally, in terms of Piaget's theory of stages of development of intellect, they do not operate at the operational (4th) stage.

A diagnostic test of prior knowledge was also given in 1979 and 1980 with some emphasis on concepts of motion / mechanics and direct current electricity. I have tabled in the diagram/figure below a sample of questions from these questionnaires. To the right is the percentage of students responding to each possible answer and distractors. The number of students who took this test was 325 in 1979 and in 1980 it was 211.

		% Student Responses 1980
D. If a body is moving along a straight line traversing equal distances at equal times, the force acting on the object is:		
* (1)	Zero	47
(2)	Constant but not zero	44
(3)	Increasing at a constant rate	7
(4)	Decreasing at a constant rate	2
G. If the velocity of the body is increasing at a constant rate, the acceleration is:		
(1)	Zero	3
* (2)	Constant but not zero	46
(3)	Increasing at a constant rate	48
(4)	decreasing at a constant rate	3
H. If the velocity of the object in F is increasing at a constant rate, the force is:		
(1)	zero	6
* (2)	Constant but not zero	41
(3)	Increasing at a constant rate	46
(4)	Decreasing at a constant rate	7

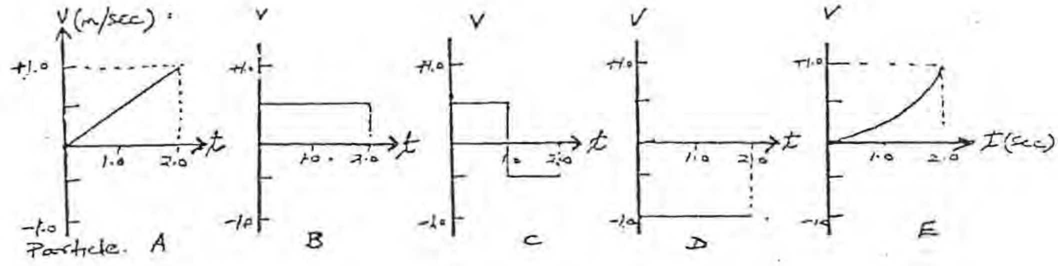
5. If a rocket moves directly up at a constant speed, then as it moves up its kinetic energy is:		1979	1980
(A)	Decreased by more than its potential energy is increased	35	12
(B)	Decreased by the same amount as its potential energy is increased	30	50
(C)	Equal to zero	3	6
* (D)	is unchanged but has a definite value	25	26
(E)		7	6

In question D, although the largest number of the students, 47%, have given the correct answer (option 1), a very significant minority, 44%, think that a particle moves at a constant velocity in a specific direction only because there is a resultant force acting on the particle in that particular direction. This incorrect conception is quite disturbing. The problem in question G is with the understanding of acceleration in terms of velocity, and also more fundamentally that of sorting out acceleration as a rate. Here the largest percentage of the subjects, 48%, assume wrongly that if the velocity is increasing at a constant rate then also the acceleration is increasing at a constant rate. Also in question H the largest proportion of the students tested, 46%, of the students (N=211) assume incorrectly that if the velocity is increasing at a constant rate, then the resultant force acting on the body must be increasing at a constant rate. The more appropriate answer would be that the force has a constant value. Students have a marked difficulty in sorting out rates and physical quantities defined in terms of ratios, and this permeates throughout all sections of the physics course.

The last question on the kinetic energy of a rocket [question 5] serves to illustrate how students grab at an idea [kinetic changes to gravitational potential energy], espoused elsewhere in a different context, and use it without thinking deeply about it. This tendency suggests that at the schools level students are probably drilled in certain thumb rules according to which physical systems operate. My opinion is that they find it hard to get rid of this fixation and generally try to apply thumb rules to most situations without reasoning specifically about a particular context.

I also asked a question involving the motion of particles and the interpretation of this using graphs.

Question 4 to 6 relate to 5 (five) particles that start at x=0 and t=0 sec and move in one dimension independently of one another.
Graphs of the velocity of each particle versus time are shown below:



4. Which particle is farthest from the origin? at t = 2.0 sec? E. (E)

A. (A)	B. (B)	C. (C)	D. (D)	E. (E)	
33	8	6	16	37	% Responses 1980

5. Which particle moves with a constant non zero acceleration?

A. (A)	B. (B)	C. (C)	D. (D)	E. (E)
63	17	3	4	13

6. Which particle is in its initial position at t = 2,0 sec?

A. (A)	B. (B)	C. (C)	D. (D)	E. (E)
2	20	69	7	2

From the responses in brackets we can see that students do not relate to motion of a particle as represented in terms of graphs.

In formulas and physical relationships expressed symbolically in terms of formulas, students have the tendency to assume in error that the quantities represented are related linearly in a simple way or directly proportional. They do this obliviously, even when the relevant formula which could help analyse the situation has been given. One has only to look at the examples / questions and responses given below to verify this.

7. The force of attraction between two charges can be doubled by:

		% Response 1979	1980
A.	Halving the distance between them.	56,6	56,9
B.	Doubling the distance between them	6,2	8,1
C.	Doubling the charge on both objects	18,2	16,9
* D.	Doubling the charge on one of the objects	15,4	14,6
E.	[students did not choose any of the above]	3,6	3,5

Given $F = \frac{k\,Q\,q}{R^2}$

9. Two spheres A and B have charges on them

[A] q •- - - - - 4 meters - - - - - - - - - - • 2q [B]

as shown in the diagram .
How does the magnitude of the force exerted on A by B compare with the magnitude of the force by B on A ?
The force on A is

		1979	1980
A.	four times the force on B	3,7	6,9
B.	two times the force on B	22,8	18,8
* C.	the same as the force on B	14,8	13,1
D.	half the force on B	49,5	51,3
E.		9,2	9,9

20. The resistance of a given fixed length of a metal wire of circular cross section is R. A second wire is made from the same material, same length but with a diameter two times that of the original wire. The resistance of the second wire is:

		1979	1980
A.	4R	3,4	8,0
B.	R/2	43,0	38,5
C.	2R	27,4	28,8
* D.	R/4	6,8	5,4
E.		19,4	19,3

Given: $R = p \frac{\text{length}}{\text{Area of cross section}}$ where p = resistivity of the material of the wire

This particular diagnostic test was given both in 1979 (N=325) and in 1980 (N=211), and one can notice immediately the agreement in relative percentages of the responses given in 1979 and 1980. In both years quite remarkably students show the same tendencies of ignoring the formula given, and in assuming a linear relationship or direct proportionality between the relevant physical quantities. In question 7 the equation kQq/r^2 is actually given but the majority of the students try to relate the doubled force linearly with a doubled distance between the charges. The same approach is naively used in question 20 later on.

The responses significant in questions 7 and 20 lead to very serious misconceptions in direct current electricity theory. It is very important to correct these at the onset whilst still at the embryonic stage. The response of the largest number, of the subjects tested, in question 9 is also not correct and highlights the problems that students have with Newton's thirdlaw: The force on A is equal in magnitude to the force exerted on B, and option C. is the more appropriate choice. In error a very large number of students use instead what I shall call the 'dominance principle' and assume that the charge that is larger exerts a "bigger" force.

2.2.0 Diagnostic Testing of Electricity Concepts: using multiple choice questions

The research literature on misconception studies in physics education reports extensively on misconceptions in mechanics. Studies related to reasoning abilities of students in physics and other related disciplines at university level have been extensively reported, especially in the United States. I have discussed these briefly in the overview of the research in the past chapter. Types of standardised tests for intellectual maturity level have been developed. It is certain that physics and science education research in this country could benefit greatly from this work and could even use, with slight modifications, some of the test instruments evolved elsewhere with some success.

Instead, I have chosen to search for misconceptions in the area of direct current electricity, because I believe that in misconceptions research I could cover virgin ground.

This would be especially relevant for the student that I am involved with because his mother tongue is not English, and a significant proportion of misconceptions arise, I believe, from use of language and metaphor as will be shown later. I will then proceed accordingly and highlight some of these misconceptions as I perceived them initially. I have gathered these in many different ways, including informal interviews, laboratory situations, from written assignments of students etc.

From the initial observations I had proceeded in the preliminary study to attempt to confirm some of these unacceptable conceptions using diagnostic tests of the multiple choice type in 1979 and in 1980. The analysis of responses to questions 9 and 20 above indicate already that the tendencies in students' thinking infringe on the more appropriate conceptualisation of direct current concepts. A further question (listed below) in the diagnostic test mentioned above confirms further that the question of representation using symbols and formula is more complicated than we would like to accept.

% Responses	1979	1980
19. A certain student wrote: "Since R = V / I is the resistance of a conductor expressed in ohms, where V = the p d across it expressed in Volts, and I = current through it expressed in Amperes, we may deduce that the resistance of a conductor increases as the p, d across the conductor; and vice versa"		
A. This is correct	43,1	42,7
B. The equation is faulty since the term V/I should be I/V	4,6	6,2
C. The statement is faulty since the statement "increases as the p.d. across .. .. " should be "decreases as the p.d. across .. .. "	9,5	10,8
* D. The logic of the statement is faulty since V and I do not change independently of each other	16,9	16,5
E.	25,9	23,8

One can see that the popular choices (of the students) in this question are in fact not correct. They do not represent a satisfactory explanation of the accepted theory. A more appropriate choice here would have been D, but only a very small number of students opted for this as the correct answer. This example further illustrates that the students always assume that the relationship between V, I and R is dictated by the equation $V = IR$ in a rather simple way which is detached from the reality of the circuit components. The equation is a very powerful tool in the conceptualisaton of students, unfortunately it is overused by most and often misused, as in this case. The V and I do not change independently of each other. The largest number of the students in this case chose option (A) which is not correct; and this choice indicates that subjects tested were just applying the equation $V = I R$ in a simple and straight forward way. The basic theory does not accommodate this misconception; V and I do not change independently, and there are other factors (parameters) which come into play here.

The responses to question 15 indicate that it may not be taken for granted that students have a completely satisfactory understanding of electric fields or as a matter of fact magnetic and gravity fields.

15. At a given point the direction of the electric field is towards the North. The force exerted by the field on a proton placed at this point is towards the

% Responses		1979	1980
* A.	North	29,2	23,5
B.	South	24,9	32,5
C.	West	17,5	15,8
D.	does not have a definite direction	11,7	10
E.	no response	16,7	18,2

In addition to the prior knowledge tests, I also gave a simple diagnostic test of concepts in electricity. The table below lists five questions from this test which become significant.

Fig. A

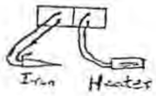


Fig. F

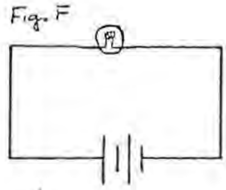


Fig. H

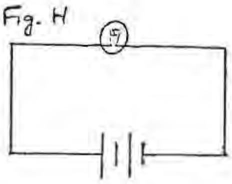


Fig. I

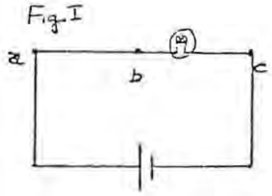
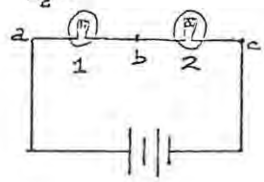


Fig. J



% Responses 1980

1. The two appliances in Figure A are wired to the mains (electric source) in parallel so that they may have the same

(i)	current in them	38,9
(ii)	operating temperature	5,2
(iii)	power supplied to them	16,6
* (iv)	voltage across them	36,6
(v)	[students did not give any of the above responses]	3,7

4. In the Figure F the filament (bulb) is shown.
The filament of the bulb becomes white hot because

(i)	the wire is wound in a coil	17,2
* (ii)	the wire is thinner than the lead wires	25,1
(iii)	the wire is shorter than the lead wires	35,7
(iv)	the wire carries a higher current than the lead wires	19,1
(v)		12,9

6. The potential difference (voltage) across lamp 1 in Fig I

(i)	will be equal to that of lamp 1 in Fig H	8,3
(ii)	will be less than that across lamp 1 in Fig H	10,2
* (iii)	will be equal to that across lamp 1 and lamp 2 in Fig J	38,9
(iv)	will be equal to that across lamp 1 in Fig J	25,5
(v)		17,2

7. In passing through a lamp in a closed circuit, [Fig F] a charged particle [carrier of current] moving in the direction of the current

(i)	gains some energy	21,7
(ii)	loses some energy	44,6
* (iii)	gains some energy and lose some energy	8,2
(iv)	neither gains nor loses energy	18,5
(v)		7,0

9. In the circuit in Fig J the electrical potential energy at point a

(i)	is lower than the electrical potential at point b	24,8
(ii)	is equal to the potential at point b	36,3
* (iii)	is greater than the potential at point b	29,3
(iv)	is equal to zero	1,3
(v)		8,3

From question (1) it emerges that students think of a power source as a supplier of electric current instead of electrical energy and, from an analysis of question 4 emerges the notion that more electric current passes through a thinner wire connected in series to a thick wire . The responses to question 6 and 9 indicate that there is a lot of confusion in students' minds about the concepts of potential and potential difference.

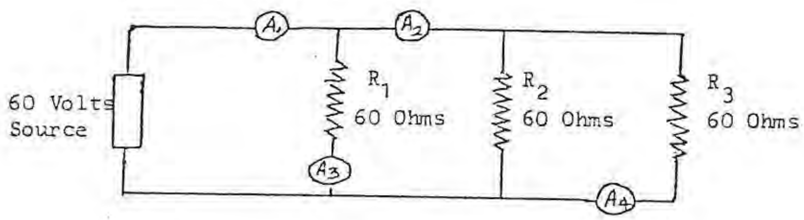
Although one naturally expected confusion about energy exchanges it was not only an eye opener but was also disturbing to find that only 8,3% of the students (N=211) chose option (iii) as the correct answer in question 7. We would expect that a much larger percentage would accept that energy is 'lost' (to the conductor) as it is gained (from the electric field) in the conducting filament. This clearly shows the theory as taught in the schools is basically along the lines that:-

energy (or electrical potential?) is gained from the battery by the charged particles and lost (or 'exchanged' to some other form?) in the resistors in the circuit progressively until the charges have no energy when they enter the battery on the other side.

This is not suited to the electric field approach to electrical conduction. Also it has some serious implications for the overall theory and leads to the (electrical) potential energy being interpreted as kinetic energy of the charged particles which kinetic energy is lost progressively as charges move in the circuit. The electric field theory approach would alleviate this problem, I think. More about this later.

I also tested in a routine class test for concepts of current flow using a simple circuit as shown below:

Questions D, E, F, G, and H are based on the diagram below:



		% Responses	1980
F.	What will be the reading in Ammeter A3 ?		
* (1)	1 Ampere	35	
(2)	2 Amperes	18,5	
(3)	3 Amperes	7	
(4)	0 Amperes	36,2	
(5)		3,3	
G.	What will be the reading in Ammeter A2?		
(1)	1 Ampere	3,0	
* (2)	2 Amperes	35,8	
(3)	3 Amperes	41,8	
(4)	0 Amperes	1[illegible],4	
		17,5	
H.	How many coulombs of charge will pass through Ammeter A4 in 1 minute?		
(1)	1	38,3	
* (2)	60	33,3	
(3)	120	5,7	
(4)	600	3,2	
(5)		19,5	

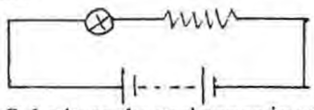
The results of this small sample of questions were quite disturbing. In question F the largest number of the subjects tested, 36,2%, (N=211) felt that the electric current after the resistor is equal to zero, that the value of the current is not maintained constant in a series circuit. I interpreted this to mean that the electric current is "used" by the resistor. The next question does little to dispel my anxiety that the majority of students do not understand direct current theory; only 35,8 % opted for the correct answer. In the last of these questions (H) the distribution of responses is fairly even between the first two choices, and again the majority of the students (100% - 33,3 % = 66,7%) do not know the correct answer. The responses to this question suggest that electric current does not register in students' minds as a rate of passage of charge. It is very likely that the majority chose option (i) just because they figured out, using simplistic reasoning that one ampere will be read from meter A4.

2.2.1 Use of Laboratory practicals in diagnosis:

The first year practicals scheduled routinely for one afternoon a week were used for informal interviews and in depth testing for conceptual positions of students. Some of the routines were structured in such a way that students had to write their responses down and these write-ups would be scrutinised later on for misconceptions and other common sense theories. The table below indicates the format of a section of a practical session that would form part of an afternoon's work. It also gives a couple of responses that turned out to be interesting.

Page 58

Part G - RESISTORS AND DIODES



(a) Connect up the circuit above. Substitute the resistance in series with an ordinary wire. Note the brightness of the lamp.

OBSERVATION:

The lamp is brighter after the resistor has been removed.

ACCOUNT FOR YOUR OBSERVATION :

When the resistor is connected, more current is consumed by the resistor. That is why it is less by the time it {current} gets to the lamp

(b) Reconnect the resistor R. Reverse the terminals of R. Note the brightness in each case.

OBSERVATION:

No change

ACCOUNT FOR YOUR OBSERVATION:

(c) Connect the diode D in the pace of R. Reverse the terminals of the diode D. Note the brightness of the lamp in each case.

OBSERVATION:

ACCOUNT FOR YOUR OBSERVATION:

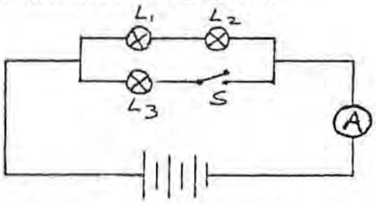
Page 59

PART H - MEASURING CURRENT :

Connect up the circuit below with an ammeter A in the circuit

(a) with switch S on

(b) with switch S off



In (a) and (b), measure the current [on A] and the potential difference between the points a and b. Note the brightnes of the lamps.

OBSERVATION :

Lamp 3 is brighter than the lamps L1 and L2

ACCOUNT FOR YOUR OBSERVATION :

Comment on the brightness of each of the lamps L1, L2 and L3, before and after pressing the switch.

--- because the current passing thro' the lamp 1 and lamp 2 is the lamp {equal} as that passing thro' L3.
Thus lamps L1 and L2 use only half the current passing thro' L3
They have to share the current.

From the first one of these (part G), it is obvious that the subject thinks that electric current is "consumed" by each component of the circuit; an interesting observation. With regard to the second one (part H), the suspicion is that the student thinks of the battery as the "supplier" of the flowing electric current which is then automatically channelled in equal parts at the branch off, one part to the branch of L3 and the other to that which has lamps L1 and L2 in series. This is also unacceptable thinking although it has given the correct answer in the end.

At this stage I felt there was a need for more in depth investigations of the students' preconceptions and misconceptions around the theory of direct current electricity, particularly in order to look at those preconceptions and alternative conceptions or student theories that lead to scientific theories incompatible with those theories generally regarded (by the scientific community) as being appropriate. My projection was also to catalogue these student theories and hope to construct / suggest some instructional and other intervention strategies to accommodate them.

2.3 Why the personal Interview?:

After the preliminary investigations on student preconceptions and misconceptions, I felt that it was essential to get more than a mere catalogue of the conceptions of students. Whilst from the multiple choice diagnostic test questions, and the written assignments; one could well get a good feel of what the problems were on a broad basis, it also became clear to me that merely identifying the alternative concept held by a student does not automatically tell us much about how the student intergrates it or accommodates it with 'older' concepts in his schema or thinking structure. Secondly I realised that I could not hope to find out how the student will use the alternative conception in working out problems or to sort out other conceptual situations that challenge him. There was a need to identify the students' strategies in his use of the alternative conceptions to accommodate other significant concepts. Because of the reasons stated above and other more subtle reasons, I decided that it was most essential to conduct personal interviews with smaller numbers of a preselected spectrum of students.

In the past ten years there has emerged amongst researchers in science education an ever increasing interest in determining what and how a person thinks. This academic discipline is generally referred to as "Cognitive science". As a technique for gathering data the personal / clinical interview has become a very powerful and popular instrument in this field of research. Cognition scientists believe that it is possible to model a person's cognitive processes, through the procedures of gathering data from holding an interview with that person [Fredette, 1981]. The initial interview could be followed by a series of adaptive follow-up interviews if this becomes necessary, in order to probe the subjects' initial responses.

The interviews were much like regular conversations in that the student did most of the talking and the interviewer - instructor tried to probe the student's understanding with short open-ended questions such as

Can you tell me the reason for this?
Why do you say so ?
How do you know ?
How did you work that one out? -and so on;

Invariably the kind of reasoning involved in the exercise would lead to fundamental conceptual and reasoning difficulties and would bring out the flaws in their reasoning.

A basic character of the interviews was that they were allowed to flow naturally. The person being interviewed was allowed all his say and the interviewer would only probe afterwards, in order to test the hypotheses which seem to evolve from the student's responses. If it is not done in this way there is a strong possibility that some influence would be injected into the logic of the person being interviewed. The appropriate intervention should occur only when the interviewee has ceased making spontaneous remarks.

One had to be careful that whatever is asked next must be a reasonably articulated next step of the subject's response to the previous question. Whilst from the interviewer's point of view the questions had to be ordered they were not so rigid that they could not be asked in some other way more appropriate to the circumstances ruling at that moment. It was important that the interviewer should not set himself up as an authority, that all points of view aired were equally and open endedly valid for the purposes of the interview. It was also important to make the interview as informal as possible, to indicate that it was not a test and that it would not be used against the subject in any way afterwards. Care was taken that the interview was not so long that the student would get tired, and every effort was made to make it have an intrinsic interest to the extent that the student should be excited intellectually by it.

Although the interviews were conducted essentially in English, the students were free to use any other indigenous language which was common between them and the interviewer. The students could spontaneously switch to the vernacular and this arrangement was rewarding. Another bonus of the interview method was that I was able to get non-standard and non anticipated responses. A remarkable feature was that I found the majority of the students very keen on follow-up interviews hoping, I assume, that they could in these later interviews resolve their conceptual problems. It also became much easier for them to consult me afterwards even on other aspects of the physics course.

The open-ended personal interview broadly described above, was the main research tool used in the investigations. Whilst this is so, I must hastily emphasise that the interview was used as an extension or natural outgrowth of the other methods used and reported earlier. Whilst follow on interviews were used, some in a practical situation, there were also other reasearch techniques which were used to a greater or lesser extent. For example, the concept mapping technique was used as I had confidence that it would portray more appropriately how the individual students saw their own conceptions linking up to form a wider overall picture of the relevant natural phenomena. I also used concept mapping as a technique for gauging the effect of intervention strategies I had evolved.

The conclusions of the investigation will depend on the whole picture that was gathered using the different methodologies with the dominating one being personal interview. In the following chapter is documented, more elaborately, the processes and findings of the classical interview method.

CHAPTER THREE:

RESULTS

3. Introduction:

This investigation was initiated against a background of quite a few strongly held views on the factors that may influence and affect the development of physical concepts amongst students entering university science courses.

(i) The incoming matriculants are not adequately prepared; their mathematical and technological background and general experience, is not deemed to be satisfactory. Inputs from students indicate that the preparation in the schools has been directed almost exclusively towards the passing of examinations, the stress in learning being on memorisation and rote learning. This pedagogical tradition of rote learning, needless to say, inhibits the drawing of any necessary distinctions between myth and science and generally hampers the natural assimilation / development of physical concepts.

(ii) There are many worthwhile investigations which have indicated that a large proportion of the students at the senior secondary school level and at the tertiary level may not be capable of consistently using formal reasoning in particular science content areas for the understanding of concepts presented in books and by teachers, [Arons 1976/9; Cohen et al 1978; Le Boutet-Barrell 1976; Prosser 1979/83]. The ability to reason in abstract terms is a manifestation of cognitive development and has been shown to correlate significantly with performance in physics tasks, [Barnes 1977; Renner and Lawson 1973]. Some studies have in fact judged most of all the major concepts in physics as being abstract, [Prosser 1979]. It certainly does appear to us that abstract thinking is important in the understanding of certain concepts in electricity like potential, potential energy, fields, electric current etc. The students have to sort out a submicroscopic scene of accelerating electrons and try to relate these to the overwhelming observable effects / evidence of electricity like shock, light, heat, etc; and in many cases are not able to deduce or reconcile these with the behaviour of the charges, electrons etc.

(iii) There is merit in taking a second look at the traditional philosophical outlooks of the students we teach. Some educationists have expressed the view that the problem of misconceptions, and scientific outlook in general, is compounded by the general superstitions, beliefs and traditional worldview of black students, [Seretlo 1980; Whittles 1980]. A man whose traditional background places some emphasis on myth and superstition, and who himself places unquestioning belief in people in authority or those who stand on a higher social and academic pedestal in the social system, is very likely to accept without questioning what he is told. It may not even occur to him that he has to try to understand what is 'taught'; and he is not likely to learn anything as such. In some traditional cultures nothing happens without a cause but causality is often that of human volition, rather than of the material world. If a man is not able to explain something, he sees no reason to worry about it, or he simply accepts any explanation given without challenging it [Fensham 1983], however simplistic it may be. Often I have come across students who, on being asked to explain the possible cause of common occurences of static electricity, reply by saying 'idaliwe' meaning that it was created by God to be like that.

(iv) There is also the traditional outlook held by some students that phenomena have a unique explanation. That new information or outlook may be gained from further observation or experimentation etc; and that knowledge is expandible, are all at variance with traditional belief. Traditional belief holds that all knowledge may be obtained by looking it up or by asking the elders or gurus in the society. Naturally here we are faced with the possibility that assimilation of science knowledge / information will be in the nature of copying the form rather than adopting the spirit, a strategy that side steps the fundamental conflict.

Teaching science in a developing country Shrigley [1983] found students, who were seeking simple answers to complex scientific phenomena, distressed by the tentative nature of the scientific enterprise. There was a tendency, he says, to embrace, even with tongue in cheek, information having a superstitious base but definite answer, in preference to wrestling with several scientific alternatives. One student even demanded that he teach only those things that scientists were sure of.

(v) Closely linked to the effects of textbooks, teachers, language and words, on the transfer of information, is the use of models, which although satisfactory at the beginning outlive their usefulness and tend to restrict the meanings of the concepts intended [Bullock 1979]. Students construct their own models as they learn and interpret physical phenomena and interact with instruction, [Pope and Shaw 1981]; and it is important that teachers are aware of these, and help students in this process. We have to be mindful that some of the models that we refer to here may actually be the personal constructions of the students themselves.

(vi)

For those students whose mother tongue is not English, there may also be the problems with linguistic transfer and metaphor. Words like force, energy and power translate to the single word 'amandla' in Xhosa. Electricity (current and static) translates to 'lightning' in most languages in Southern Africa; not only in the meaning but also in the superstitions held by some students on lightning.

3.1 Statement of Purpose:

The purpose of this particular investigation was to examine in some detail the alternative conceptions that students entering first year university courses hold about certain concepts in the electricity section of the physics course, in particular direct current, electric potential, potential difference, short circuits, energy etc;. The selection of these concepts developed naturally from the exploratory diagnostic tests mentioned earlier and also adaptively from the initial interviews. The term 'conception' is used here as a descriptor of the ideas which come to exist in a person's mind as a consequence of his efforts to interpret the environment.

In addition an attempt was made to find out why the student held the particular preconcepts and misconceptions, and whether, in fact these were coexisting with formal scientist s' science. We also tried to establish if the particular alternate conceptions come to be, not only from the formal educational background or schooling but, perhaps also from the socio-cultural background, and to what extent the world view of the student affected the formation of concepts. The emphasis was on identifying the significant student inappropriate conceptions and in obtaining a qualitative description of the cognitive models that emerge rather than to establish accurate percentages of students who had these inappropriate conceptual structures.

3.2 Methodology:

Various methods have been used to elicit "children's science" and alternative conceptions, for example the use of Multiple choice questions, open response questions and the use of real world settings [Helm 1978; Nussbaum and Sharoni 1983]. Some of these have been reviewed earlier. Gilbert and Osborne [1980] here have introduced the Interview about Instances technique which consists of tape recorded discussions with a student using as a focus a deck of cards concerned with the application of the word. The interview technique has also been used productively by other research workers, [Klein 1982; Johsua and Dupin 1987]. It is one of the most powerful techniques in cognitive science studies (Duit & Jung 1984). It elicits more than a superficial response. Further, questioning in an interview often reveals that the student in fact does not understand the concept or has a limited or incorrect view of it. There is the added bonus that in explaining, students may come up with the most curious explanations that the interviewer would not have even dreamed of testing for.

The research data reported in this chapter was gathered through the use of interviews. From a study of the interaction between the researcher and the student as reported in the protocols a theoretical model of the cognitive processes of the student is constructed. When the interview technique is used, every probe and response as recorded has to be accounted for in the theoretical model that is eventually constructed. Although this was done it was, for obvious reasons, not possible in this project to table every one of these and instead, certain typical protocols and extracts are tabled for more rigorous analysis.

The initial interviews were conducted using pictures and diagrams of simple electrical circuits and later using real world settings of the concepts concerned.

3.3 Procedure:

The main investigation was carried out on random samples of first year students during the years 1980, 1982, 1983 and 1984. The students were doing the Physics 1M (Medical and Biology) and Physics 1A (Ancillary) courses in the Physics Department of the University of Fort Hare. These two courses are terminal and constitute by far the largest proportion (85%+) of the total first year intake each year. All the subjects interviewed had received formal teaching in Physical Science at the school level and were familiar with the theory around direct current electricity, with the applications of Ohm's law to single loop circuits etc; and to simple aspects of static electricity as taught in standards 9 and 10.

Each student was interviewed individually. The interviews were audiotaped, to be analysed later, and usually lasted about 40 minutes. No attempt was made to cover the whole ground each time but certainly those aspects which seemed to yield something. Consequently I will not be reporting on everything that each of the subjects knew about the section of electricity chosen for this study. There were follow up interviews if this became necessary. The majority of those interviewed volunteered for the sittings; others were interviewed informally whenever they came around looking for help in their work. The opportunity was always given, and the chance awaited for the spontaneous explanations behind the thinking. Attempts were made to establish if the reasoning was consistent or had a definite pattern.

3.4 Results:

The results presented here are some typical responses and certainly do not include all those students who were interviewed. The report as such is a qualitative analysis and no attempt has been made to quantify the responses. Naturally though the responses cited were those most significant, frequent and typical, I have chosen to present the alternative frameworks, which I have diagnosed, in two ways:

(i) I have attempted to group the conceptions of the students into specific topic areas and to make comments on the alternative frameworks or perspectives that seem to emerge in those specific theory situations. In this way I have been able to highlight certain curious aspects of students' thinking which I thought were being indicated by the responses from the students.

(ii) The comments from (i) are illustrated by extracts from the responses of the students, with probing questions by the interviewer indicated as such or in brackets.

A couple of these frames were used directly from the work by Osborne and Gilbert [1980], and some of the others were initially stimulated through ideas from other published work, for example Rachinger [1973].

3.4.1 Conceptions related with Electric current and its flow:

As I have mentioned earlier the interaction between the interviewer and the student was basically informal. In the interviews one question followed another but the sequence from interview to interview did not always follow the same routine pattern. As a result of this I have grouped the results from the frames that follow according to the inappropriate conception that the particular students seemed to highlight.

The main purpose of the first frame was to test fundamental notions about the nature of electric current. A picture of a car battery, not connected to anywhere, was presented. Figure 1

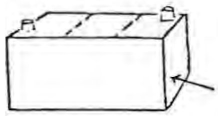


Figure 1(a)
Is there electric current in the battery?

Some of the students interviewed did not seem to realise that electric current implies the flow of charge; some seemed to think that the battery, by virtue of the fact that it was capable of 'producing' electric current in a conductor, does contain or have the current inside itself.

S.13

> .... if the battery is fully charged then there is a current in it even if it is not connected to an outside circuit. .. ..
> There is a stationary current in the battery although the battery is not connected .. ..

S.23

I. How do you know that the electric current is in there ?

S. .. it is difficult to know if there is a current unless you test for it.

I. How would you test for the presence of electric current in the battery?

S. By connecting an ammeter to it. .. since I have now tested it I can now say that there is a current in the battery.

The current is stored here in it.

S.25

There is electric current in the battery .. .. the electrons come out from the electrolyte in the battery.. The wire does not have the electrons..

S. 21

I dont think that it is there .. .. even if it (current) is there, it is in a state of rest

S. 6

There is current electricity in the (unconnected) battery but it is not flowing

S.24

I think that the current is stored in the battery .. so that when the bulb is connected it will light ..

If there is no electric current in the batteries we would not be using them to get light in this bulb.

In the next frame a lighted lamp connected to the battery terminals is shown. In this frame I wanted to find out if the respondents thought there was in fact electric current flow through the battery itself, accepting that there was a current flowing through the lamp in the outside circuit.

Figure 1 (b)

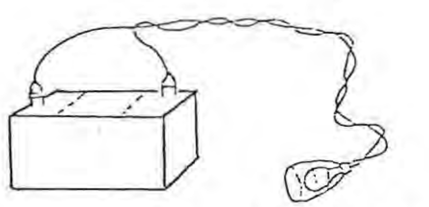
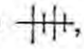


Figure 1(b)

Is there electric current in the battery now?

It seemed that, although most schools have converted to the positive charge conventional current flow model, most students resort to using the flow of electrons in trying to explain what is physically happening when the current flows. I have allowed this at all times since the ultimate purpose of this effort was to find out how students thought.

A considerably large proportion of students thought in terms of electric current only flowing in the outside circuit, certainly not through the battery itself. It seemed that some were influenced by the physical structure of the battery as they perceived it, and also by the symbol for a battery  as opposed to , which some would have rather preferred since the latter symbol indicates continuity of the circuit and of the current in the circuit.

S. 17

> The electric current is in the lamp.. ..
>
> This terminal is separated (on the outside) from this one ..
> I once saw a battery (dismantled) .. a motor car battery.
> The plates of it are not connected, they are separate
> They (the electrons) come from this liquid .. ..

I. So when the current circulates this means that the current passes through the battery?

> No! .. It is the battery which gives out the current
> (Yi Battery ekhupa i current)

S.14

> I would say that there is no current in the battery although there is a current in the outside circuit. .. .. because the chemicals are separated.
>
> I think that a battery has many separate compartments

S.18

> It (the electric current) is in the circuit (not in the battery)
> The charge flows from the positive terminal to the negative ..

S.23

Current starts to flow from the battery and goes to the lamp
and then the bulb glows .. otherwise the current is stored
in the battery
(it does not pass through the battery)

S.25

When the electrons move from this side they neutralise
the positive charges on this side (positive side of
the battery) .. .. putting this thing neutral

It became clear from the last section that certain students think of electrons (and hence current) as being lodged in the negative terminal of the battery, moving through the conductor only when the connection is made and later on nuetralising the positive charges on the positive electrode. I thought it worthwhile to investigate how these charges (electrons) flow through the conducting wire.

S.4

Electrons come from the battery .. . are stored in the battery

S. 1

By the time you switch off the electrons, which are
of a very high velocity, will have already moved to
the battery ..
There will be no electrons in the wire when you have
switched off

S. 5

The electrons move with the speed of light .. ..
they are always moving at the same speed (rate)

S.21

One electron here (-ve terminal) pushes one electron in
the wire which will push another etc; .. .. until one
electron enters the positive pole.

It (electron) pushes other electrons because it has just
got energy from the battery

S. 5

[because of the energy they just got from the battery] the electrons cause the electrons in the wire to move on .. . The electrons coming from the battery use their energy to push the others.

I. What about the energy of the electrons when they get to the positive side?

S. Yes, the electrons from this end will be exhausted and the thing will stop functioning after some time ..

S.18

Immediately one charge enters from this side (or resistor) it's going to push the one next to it etc .. until the last one enters the battery

S.25

They (the electrons) are many .. . they move because they are being attracted by the cations in the conductor .. and by the positive side of the battery

They (electrons) are being neutralised at this (+ve) side

I. Where does the battery get the electrons?

S. The electrons come out from the electrolyte in the battery They are always staying there .. the wire does not have them

I. Why?

S. Because the battery has been charged .. .. yes after some time the battery is no longer full (fully charged) and there is no current in the circuit.

There are some important ideas, frameworks which I found are held by students and which become salient later on. I decided that it is a good idea to introduce these ideas at this point because they seem to form the basis of their explanations in the later sections of this investigation.

The first one of these concerns the characterisation of electric current in terms of the speed of the electrons flowing in the conductor.

S.18

Electrons or charged particles lose or gain kinetic energy on passing through a resistor in a circuit.

Yes on passing through the resistor the electrons will lose some of their kinetic energy

Current enters with a certain speed .. .. the resistor will act like a friction force and will retard the speed of these charges entering.

That is why the current is less on the other side of the lamp

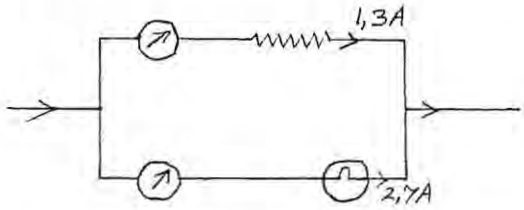
S.16

The electrons gained kinetic energy as they passed through the battery

S.13

electrons move more slowly in the wire when it has a higher resistance

I. What happens when the electrons come to the junction of these two parts?



S. There will be different currents in this part

I. Why?

S. The currents in the lamp and resistor will be moving with different velocities in these parts Here (after the junction) they will have a combined or mixture of velocities

S. 7

The electrons move along (the wire) because they have enough kinetic energy (gained from the battery)

S.16

The electrons gained kinetic energy as they pass through the battery. .. .. the current loses kinetic energy on passing through the resistor

The implication here is that the faster the electrons at a particular point, the higher the value of the electric current at that point. The other implication is that at some other point beyond the resistor the electrons will be slower and therefore the electric current will be of a lesser value, and this is not a satisfactory way of looking at this process.

The second idea concerns the amount of charge involved and the issues of conservation of matter and charge as current passes through a resistor.

S.25

Since there is a resistor the current is going to part with some electrons here .. .. sort of gain more electrons from the battery

S.2

Often the current loses some of its electrons on passing through a resistor / conductor

My guess is that the explanations are formulated in order to rationalise an existing incorrect conception. I do not think these incorrect ideas follow from muddled thinking. I will now describe this misconception:
In the background the fundamental incorrect conception is that electric current diminishes or is lost as it passes the resistor or lamp. This current is lost, it appears, as the kinetic energy of the electrons becomes less after the resistor; or in other cases the current is lost as the charge (or even electrons) become less on the other side.

Students certainly find it easy to imagine the energy of the charged particles (=electrons) to be kinetic rather than electrical potential energy; one assumes they can easily figure out in their minds energy gained or lost if it is energy associated with actual movement. Kinetic energy is perhaps the only form of energy that students relate to easily.

In passing let me mention a rather curious feature of the thinking. A circuit component whose presence in a circuit may be indicated by a resistor symbol{—ww—} is never regarded as such by the majority of the students. A resistor in a circuit is understood to be a wire resistor (variable or not) put into the circuit solely to regulate the flow of current. The other components then use the current (swallow it up).

By far the majority of all those interviewed believed that electric current is consumed by the resistor in an electric circuit. Many felt that a lamp, because it gave off light, consumed more electric current than an equivalent wire resistor presumably because nothing appears to be happening at the wire resistor whereas at the lamp light is given off. It was most disturbing to find out that a very large proportion of interviewees felt that electric current 'before' and 'after' a resistor / lamp can never be the same, because some of the current must be used by the resistor. This was the most fundamental and crucial conception which was not understood correctly by students. More than 80% of all those interviewed felt this way, and this included students who routinely scored well above average in class tests and examinations. The loss of electric current on passing through a resistor was understood by some students to happen because the speed of the electrons is reduced on passing through the resistor. Other students understood that the current is lost because some of the electrons (or charge) are used (is suddenly not there afterwards) and lost to the flow. Current lost to the resistor is turned to light and or heat etc. There was a hint that light in this context especially, was not understood to be energy really but as some other thing that happened coincidentally. So the principle of conservation (of energy) was not the guiding wisdom here.

The frames used in the analysis that follows were largely those shown in Figure 2 below:

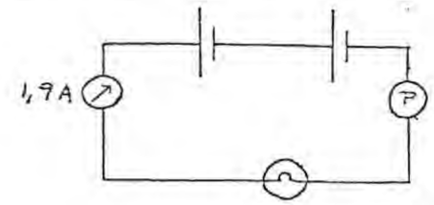


Figure 2(a)

The current shown by some ammeters is given
What is the current shown by the other ammeters?

I must emphasise though that the inappropriate conceptions relating to the "use" of electricity permeated many other frames directly and indirectly. They are a fundamental inappropriate framework that students use.

S. 12

The electrons, when they get there they turn into light..
the electricity which goes to the lamp is being given
off by the lamp as light

S.11

Some of the electrons are used and those that go through,
will be used afterwards in this part

S.25

Since this is the resistor the current is going to part
with some electrons here .. .. sort of gain more
from the battery

I. Why do you say the electrons come from the battery?

S. They come from this [negative] electrode.
This electrode has more [excess] electrons .. thats why
it is negative.

Some of the current is taken up in the lamp.
It (the lamp) converts it to energy with which it is
going to give out light.

S. 8

The current is less because some of the electric current is lost (in the lamp) .. .. because some of the electric current has been transformed into another form of energy which is light.

S.17

Ukuthi some current has been used in lighting the bulb (How used ?) ..

a thing which has more resistance uses more current

S.7

If there is a lamp here the current would be less on the other side .. .. but if there is a resistance (resistor) it will be the same .. ..

because the current is lost in the lamp

The other amount will be used by this lamp (Figure 3)

S.21

The current in P will be less than 1,9 Amps .. mos this is a negative pole, current leaves from the negative pole, and the current will first pass here [this lamp] and will be brought down by this lamp .. ..

since the lamp has a resistance the amount of current will be reduced
(reduced by the value I=V/R)

S.23

then current will be less than 1,9 Amps .. ..
(the cause?)
the resistance of the lamp .. ..

the current is used by the lamp

S. 24

The current will be more than 1,9 Amps .. .. because it moves from negative to the positive (terminal) so the voltage is increasing from negative to positive

S. 8

the reading in P is going to be higher since the current flows from the negative side and the current dissipates in the lamp

S.24

It (the current) will be less than 4.0 Amps in Y [In Figure 2(b)] because it has been used by these bulbs here (that come between)

Mh! ..this 1.3 Amps it is because it is used by this bulb

Some students suggested directly that on coming to a junction electric current must split into two (or more) equal (underlined) amounts directed along the two or more directions. This would be true whether the two resistors in parallel are equal to each other or not. I viewed this initially to be just purely a problem of language and metaphor caused by the tendency of teachers to say current 'divides' on getting to a junction. Most of the indigenous languages do not cater automatically in translation for unequal division, so divide always implies into equal parts. We will comment later on other possible reasons.

The following comments by students refer mainly to the circuit diagram shown below.

Figure 2 (b)

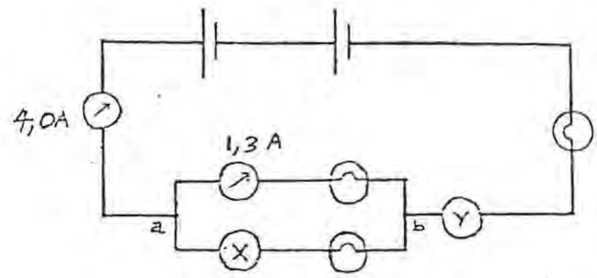


Figure 2(b)

What is the current shown by the other ammeters, X and Y?

S.17

The current in X will be 1.3 Amps .. .. because it is connected in parallel with the other lamp that is 1.3 Amps. .. .. when the current goes here (junction) one half goes to this side, the other half goes the other way

I. What would happen if there was a resistor of equal value to resistance R in parallel with this lamp??

S. .. the current in X will be a half irrespective of the fact that R is now less than the resistance of the lamp

S.21

No!! .. the distribution of the current does not depend on the value of the resistors .. .. the reading in X will (always) be 1.3 Amps

S.23

Because these are in parallel then the current is divided equally here

(WHY?) .. since they are parallel

S.15

I think that it should be 1.3 Amps because it is connected in parallel with this lamp. I think this is so because they are connected to the same points it M U S T also be 1.3 Amps.

S.25

It reads 1.3 Amps because these are connected in parallel

I. Are you not worried that 1.3 Amps and 1.3 Amps do not add up to the 4.0 Amps indicated here ??

S. No! .. .. it is possible that there is some resistance occurring/happening (eyenzekayo) here at the (junction)

In the subsequent paragraph I will illustrate how two fundamentally incorrect conceptions which we have unearthed up to this stage may merge in the thinking of students resulting in students making incorrect conclusions. The first one is the incorrect idea that current is consumed by a resistor; the second one is that resistors in parallel parts of a circuit carry equal currents even if these resistors are not equal in magnitude. What I noticed was that even some of those students who had not given definite pointers about these incorrect conceptions earlier did imply them rather forcibly in this last part.

The circuit referred to here is the one which is indicated below:

Figure 2(c)

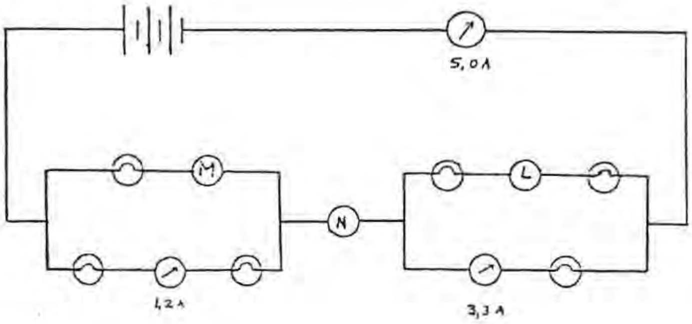


Figure 2(c)

What is the current shown by the other ammeters?

S.15

Eh! .. .. I think that the current in L will also be 3.3 Amps .. .. the light in this one (lower) will be more than the lights in these two .. ..because these two (A nd B) share the same current.

The currents in these bulbs (A and B) must give us (add up to) 3.3 Amps

S.23

Yabona (you see) the current starts by passing through this lamp and ikhona (there is) resistance in this lamp.

Some current is spent or used in this lamp. If L were put on the other side (outside the lamp B) it (reading in meter) would be greater than 3.3 Amps
[this student uses electron flow direction for current flow]

S.21

the reading in L should be equal to 3.3 Amps as it is just now, because it (the current) has just passed only through this lamp (B)

I. What happens if the position of L is interchanged with the lamp (A)?

S. Then the reading in L will be less than 3.3 Amps because
the current will have passed through the two lamps (A and B)
on this side, ... you have doubled the resistance

S.17

if L was in the place of the bulb (B), the current would
be above 3.3 Amps

I. But this means that the current has not divided equally. Yes??

S. It is (this value) because it has not passed
a resistor (=lamp) yet

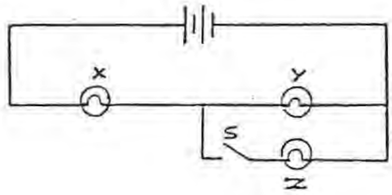
S.20

In M it will be greater than 1.2 Amps because it has not
passed through a lamp first
(unlike in the lower loop)

In this part the questions were based largely on Figure 3 below. Again I found that students expected current to be used as it passes through a circuit element. Also a new idea came up; namely that the lamp nearer the source of current will grab for itself a larger share of the current and the current will of course be weaker by the time it gets to a second or third component of the circuit. This seems to happen irrespective of the internal resistance of the circuit components.

Another conception that came out during the interviews was that the introduction of circuit elements in parallel with existing ones does not alter the value of electric current in the parts of the circuit which are in series. Again I found that students often calculate the current through a resistor mechanically by using the Ohm's law formula. Often they just divide the emf of the nearest source by the value of R to get the 'local' current through that specific R. In order to calculate the current "delivered" from the battery they will just divide the emf by the internal resistance of the battery.

In this part the questions were based largely on the figure below:




```
Figure  3

The bulbs X, Y and Z are identical
When switch S is closed bulb Y will become brighter
Is this statement True or False?  Why?
```

S.18

Now if switch S is open, Y will be brighter than X, because the speed with which the current enters X is not the same speed (meaning that it is actually smaller) with which the current enters Y .

S.25

S. Y and Z will be brighter than X .. ..

I. What is the reason for this?

S. (because) Y and Z will be of equal brightness ..(Yes) Y and Z share the current first and X will get a current which is less already.

I. Why will the current be less?

S. It will have been used up by these resistors (Y and Z)

S.21

Y and Z will be much brighter than X;

S. 6

[using the positive current flow convention]

Lamp X will shine brighter than lamp Y; (switch open) .. because it is at a higher potential, and (therefore from i=V/R) i will be bigger because the potential V is higher nearer to the battery

S. 7
Y and Z will have the same brightness .. .. but lower than X

The brightness of X will remain the same (as before the switch S was put on) since it is the same current flowing in Y and Z .. as was in Y (originally) (the current in X has not altered because the switch S is now closed)

I have found that students show a poor ability to interpret circuit diagrams. This is partly related to what they interpret to be the function of lines (and leads) that join components of a circuit. There were difficulties with whether there is only one line that 'brings' electricity to a lamp or whether for continuity of current there should be one to bring in and the other to take out the 'remaining' electric current. At this stage I have decided to highlight a few mistakes which they make; notions they had relating to parallel and series parts of a circuit.

The circuit diagrams shown below were used mainly in this section:

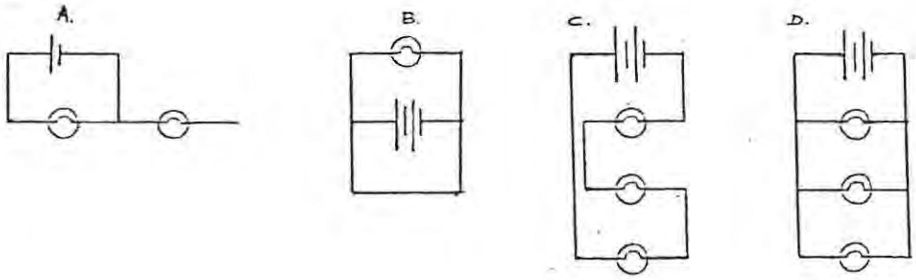


Figure 4

In which circuits are the bulbs in series?
In which circuits are the bulbs in parallel?
In which circuits are the bulbs or bulb brightest?

S.24

In C and in D the bulbs are in parallel

S.15

the wire in Figure B is neither connected in series
nor in parallel (with the lamp)

S. 5

I am now confused, I dont know [Why?]
because these things are not connected in parallel..
No ! they are not connected in series: Figure 4 B

S.25

The wire B is not in series with the lamp .. ..
neither is it in parallel

S.13

I think that if the circuit is like this (Fig 5 b)
then the current will not collide like before (Fig 5 a) ..
it will split up

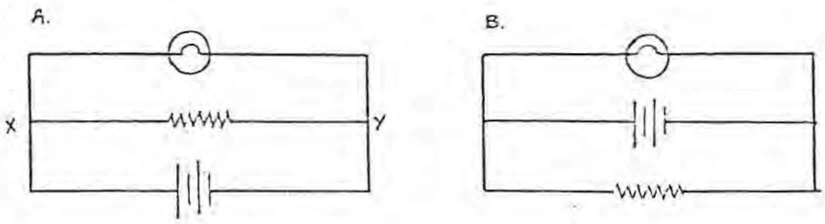


Figure 5

Are these two circuits similar?
Compare the current in the bulb in (a) and in (b)

Arising from the confusion about 'in parallel' and 'in series' connections, are a lot of incorrect conceptions in students around the idea of a shorted circuit. The diagrams in Figure 5 were included as an extension of Figure 4 B in order to explore how students understood current to be distributed in such circuits. A significant fraction of the population tested did not see Fig 5 (a) and Fig 5 (b) to be representing the same circuit. For some students the current 'chooses' to pass through the lamp or through the resistor depending which one is lower. For others Figure 5 (a) was an impractical situation. Some suggested that there would now be two currents with different speeds after the junction, and for others the currents will even collide at the junction.

For those students who felt that the electric current (from the battery) would split and pass through both the lamp and the resistor R (Figure 5 a) a greater number accepted that the current would be equally distributed if the value of R was equal to the value of the internal resistance of the lamp. However if the value of R was made less than the internal resistance of the lamp then the lower the value of R the less current moves through R until when R was (in theory) equal to zero, then the current passing through R would also be zero. It appears to me that the "zero" value of R was associated in their minds to a "no connection" between the points X and Y. Although many of those interviewed used the word "short circuit" between two points this means to them that no current will pass through the short circuit connection. A zero value resistor in parallel means that there is no connection between the points. Some recent papers have also identified this conception to be most common amongst South African students, [Allie and King 1987; Stanton 1987].

S. 11

> I think that this circuit is not possible ..5 (b).. the
> currents would clash here at the junction .. they would
> have different speeds in this part after the junction

S.13

> There would be no current because the electrons (current?)
> would collide at this point (junction) having split up
> on the other side
>
> I think that if the circuit is like this (Figure 5 (a))
> then the current will not collide like before (Figure 5(b)),..
> it will split up (.. and join up lat er)

S.15

This circuit (Figure 5(b)). is not possible.
The current will only move through the lamp.

The R must be put here (in series with th lamp)
for the current to pass through

S.21

I dont think that R will have an effect on how the current flows through the lamp [5 (a)] .. .. unless R was put in series with the lamp.

The current will move through R as it is causing a short circuit (because it is lower in the diagram) [5(a)].. .. and all current will move through R.

If you had put the lamp lower it would light .. .. and the resistance R would have no effect .. .. the current in the R (because it is upper) would not be there.

The current would tend to go through the R if the resistance is larger than that of the bulb [5 (b)]

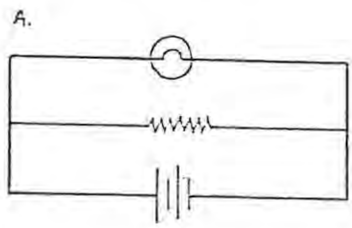
S.13

The lower the resistance R is, ... the less the current passing through that limb of the circuit 5(a) .. until the current is zero when the resistance R is zero

S.25

because it (R) has no resistance what happens will be as if there is no wire. .. .. it (the current) will tend to be larger through the lamp as R becomes smaller than the resistance of the lamp. Figure 5(a)

Figure 5.



S. 5

This lamp lights as if no wire is connected there (when there is R=0 ie; short circuit)

S.14

the lamp will light brighter if it (the wire)
has a smaller resistance (than the lamp)

In Figure 5(b)

S.17

there is some current in the wire .. but the lamp
lights very brightly

(Why?)

because it is the main circuit.. ..

I. Why is it the main circuit?

S. Because even if you take off the wire the lamp
will remain on anyway

S.23

Interviewer: So there will be no current in the wire?
[short circuit in Fig. 5(a)]

S .. No it means that less current will be wasted

(as compared to when R has an effective resistance)

But the current will still split up here;
there will be current on both sides

S. 3

a higher resistance (in parallel with another) means that
more current will flow though it than a smaller one

S.17

the current in the resistor will be half irrespective of
the fact that R is now less in value than the resistance
of the lamp

3.4.2 Conceptions related with Resistance:

We found it not possible to test for concepts of resistance without having to accept certain ideas which students used in relation to potential difference and electric current. Where it was possible we tried to deduce concepts of resistance in a functional/operational setting in the conceptual frameworks of the students. As illustrated earlier there were those students who could not sort out "parallel" and "series" arrangements of resistors. We have also indicated that some students assume that less electric current passes through the smaller of two resistors "in parallel". Frameworks about the electric current moving more slowly through a high value resistor even when two resistors are in series have been identified.

The concept of electrical resistance was in general not well developed, and conceptual links were only firmly established in terms of the Ohm's law formula V=IR.

Some typical explanations related to electrical resistors:

S. 14
I. Can you explain why the current is going to be less on this side of the lamp?

S. It is that part of the circuit which needs more energy than the other parts, ... the part to which the current is going."

When the particles (=electrons) are moving fast, on entering a resistance their speed is reduced and a lot of energy is consumed by the electrical resistance."

I. In what way is the energy consumed?

S. .. .. .. the resistor (the lamp) changes it to light

S. 18

I. Why would the lamp be dim now?

S. The current will be less .. (why?) .. because the lamp comes before it

I. So, in what way does the place of the (lamp) resistor affect the other components?

S. Resistance affects other components such as lamps as it delays [slows down] the flow of current.

The understanding of electrical resistance which students have is largely in terms of Ohm's law:

"Resistance is the ratio of the potential difference over the current.
Its ratio should be constant according to Ohm's law."

"Electrical resistance is the amount of potential difference needed per electric charge between the terminals at a given time ie; R =V/I"

Here follows some more general in context explanations of electrical resistance which were given by students:

S. 8

Where current increases the resistance increases ..

S.19

Where the current flows easily the resistance is high .. The resistance of a thin wire is higher than that of a thick wire because the current is going to flow more easily in the thin wire.

Figure 6 below refers·

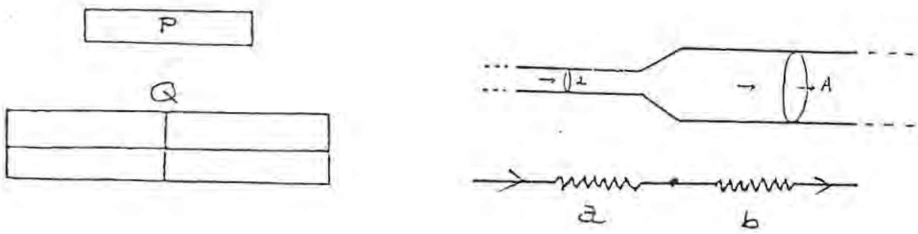


Figure 6

Metal strip P has a resistance between its ends of 6 ohms
Strip Q is twice as wide and twice as long as the first strip
The resistance of strip Q will be
A. 3 B. 6 C. 12 D. 24

S. 8

The total resistance when two metal strips are joined in series will still be three ohms .. .. because whatever current passes through A (1st strip) the same will pass also through B .. ..

and that is why the resistance is the same.

In the situation represented in Figure 6 (b) students tend to make use of the Ohm's law equation although this is obviously a situation with two resistors in series with equal value of current passing through each of the resistors, for current to be conserved. I found that most would not accept that any two or more resistors in series would 'carry' the same current. Students tend to localise the use of V=IR for each isolated resistor, using any emf source which is nearest to that resistor.

The brief protocols listed below indicate that some students think of electric current in a series loop as dependent on the value of resistance [or thickness of wire] at that particular point along the line, such that if there were two or more resistors the current would only change when it reaches that particular resistor. The assessed value of current very much depends on the speed of the charges at the point in this framework.

S.14

The current passing through a is larger than the current passing through A .. because the radius is bigger there (the X-section is bigger)

S.13

the resistance in part A is larger because it is bigger and therefore the i is smaller here (A) compared to that at (section) a ..

S. 8

more current passes through A than a .. there should be more resistance in part A than in part a .. .. since A is larger (than a)

S.18

The current passing through A will be less than the i there (in a) .. .. because the flow of current depends on the thickness of conductor ..

The electrons will be faster there in the thin part

The protocols above indicate clearly that the value of electric current at a point is thought of in terms of the speed of the electrons at that point irrespective of other circumstances. Also, a very large proportion of the students are tied to the idea that the speed of the charges (and hence the value of the current) is effectively reduced on passing though a resistor.

S.18

if the current enters with a certain speed the resistor
will act as a friction force and will retard the speed
of the charges entering

The value of the current will be less on the other side

S.14

the electrons move more slowly in the wire when it has
a higher resistance
Hence the current is smaller there

S.13

on passing through the resistance the charged particles
lose some of the energy .. .. they become less charged.

there will be less current on this side

S.16

electrons lose kinetic energy on passing through a
resistor they will have less kinetic energy .. ..

that is why the current will be less

There were other even stranger ideas about electrical resistance:

S. 7

if there is a lamp here the current would be less on the
other side, .. . but if there is a (wire) resistance
it will be the same. .. because current is lost in the
lamp
[unlike in the wire resistor where nothing (e.g no light)
appears to come out.]

It seems the resistor reduces the current, slows it down, whilst the lamp consumes some of it and changes it to light]

S.25

since this is the resistor, the current is going to part
with some electrons here .. .. sort of gain some more
in (from?) the battery

All electrons and all current come from the battery in this last framework.

3.4.3 Conceptions of E M F, "Voltage" and Potential:

I found in general that electromotive force, potential difference, voltage and potential (energy) are not fully conceptualised by students. This possibly arises because of the difficulties that students have with the concepts of work and energy even in other parts of the physics course. For a very large fraction of the students interviewed incorrect conceptions about potential difference come out from the fixation that kinetic energy of the charges is lost on passing through a resistor. Electric current flow seems to imply nothing else than the actual setting out of charged particles with prescribed kinetic energy from one point towards another, where it becomes less after passing a resistor.

In the frameworks, there were very strong associations made/drawn in error between:

loss of gravity potential energy normally accompanied by
the gain of kinetic energy (in the mechanical energy
situation)

and:

loss of electrical potential energy corresponding to change in kinetic energy (of flowing charges) in the electric circuit situation.

Electrical potential energy is visualised conceptually as a form of physical energy whose character is observable somewhat very much like gravitational and elastic potential energy. The latter can probably be imagined in terms of the observable physical state or relative position of the object whose energy is being rated. There was a hint that some students conceptualised that those charged particles at a higher potential were relatively more charged than those at a lower potential; whatever is meant by charged in this case. Potential energy as a concept eludes students as it seems that it can assume various "forms" like elastic, gravitational, electrical etc,

Electromotive force is easily understood to be a force and not energy per unit charge; a force which is applied (at the cell) to the electrons or charge carriers resulting in the gain in kinetic energy on passing through the battery. There have been many instances in this chapter where I have referred to the incorrect conception that electrons or charged particles or charge carriers lose kinetic energy on passing through a resistor and that the kinetic energy is transformed into heat or light in the resistor.

S.16

> electrons gain kinetic energy as they pass through
> the battery .. .. lose kinetic energy on passing
> through the resistor

S. 3

> the speed of the electrons will be the same here .. ..
> (at both points) .. .. hence there is
> no potential difference between the two points

This is perhaps an example of emf being thought of as a force. Traditionally students think that a body moves because it has a force within itself which will be consumed by the motion.

Very often students were not able to work out problems on current and potential differences for the simple circuits given. I found them to be always inclined to, like robots, try to isolate mechanically which formula they should substitute in. As an example, a considerable number of students wanted to merely apply Ohm's law to the circuit diagram shown below

Figure 7 (a):

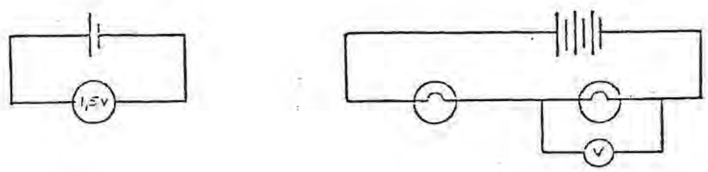


Figure 7(a)

In Fig 7(a) (i) the voltmeter reads 1,5 v
The circuit in Fig 7(a) (ii) contains three such cells and two similar bulbs. Assuming that the cells have no internal resistance the reading (in volts) on the voltmeter in Fig 7(a) (ii) will be
A. Zero B. 1,5 C. 2,25 D. 4,5

They could not work out the possible values of the potential difference across either lamp unless they were told what the current passing through each lamp was and what the resistance of each lamp was. This happened even when they were told the resistances of the lamps were equal.

S.5
It will be 4,5 volts .. .. I am not sure , ...
unless I am told what the resistance of these lamps is

S.18

V will be 4,5 volts (across the second lamp) .. it will be 4,5 also across the first lamp .. .. I don't know the current here, so I cannot calculate the potential difference across here (across both the two lamps)

S.5

I. What will be the reading in the voltmeter?
[v across lamp on the left]

S. It will be 4,5 v for this lamp .. ..
I dont know what it will be here (second lamp) .. ..
but it will be less
[less than?]

It will be less than 4,5 v .. This one is 4,5 v
because it is nearer to the battery here .. ..
nearer the +ve side of the battery

I. What about that one? [on the right] . Is it not also near to the battery?
After all it is connected to the battery as you can see

S. This is the negative side .. .. that is why it [reading of voltage] is lower,
the lamp is connected to the negative side

S. 4

we should be given the current .. .. you must know the current and the resistance (of these two lamps) to get the potential difference. It is impossible to know this p d

The emf and the potential difference across the terminals of a battery in a closed circuit are often confused. Potential difference or perhaps potential or 'voltage' is often thought of as something which is supplied from the battery to the other electric circuit components in very much the same way as current and, in students' minds, is also consumed/dissipated by the resistors in the circuit.

S.25

To my thinking some volts are going to be lost in this lamp .. .. so the second lamp will have less volts in order to light ---(meaning for it to light)
(This suggests the lamp must consume some volts)

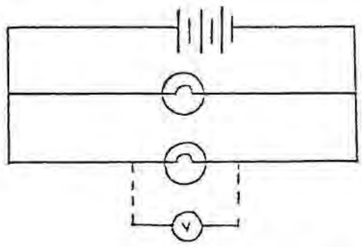
S.17

In the series case (two lamps in series) the voltmeter reading will be less in the second lamp because the current is now less than through the first lamp

S.21

The reading will be below 4,5 volts
(second lamp in Fig 7 (a))
because the current will be brought down by this lamp
(1st lamp).. .. and then the voltage
(in the voltmeter) will now be less

Figure 7 (b)



The cells and bulbs shown in Fig 7(b) are similar to those in Fig 7(a)
The readings (in volts) on this voltmeter will be
A. Zero B. 1,5 C. 2,25 D. 4,5

S.18

the V will read the half of the potential difference ..
which is 2,25 volts

I. Why?

S. .. .. these bulbs are similar, now the current at this point, the fraction of this current will flow to this direction now, so the potential difference here will be the half of the potential difference across these (two lamps in parallel) .. ..

I. Because half the current goes this way ?

S. Yes

This also implies that 'voltage' depends on current which precedes it.

S.15

its going to be 2,25 v and 2,25 v

S. 8

the voltage is going to divide .. .. the voltage is 4,5/2 since they are connected in parallel

S.16

the voltage will be 2,25 v (across the upper lamp) because, now the two bulbs are of the same kind; now .. .. now they are connected in parallel ..

You find that as the voltage comes to this point it will be divided into two equal parts.

Each (lamp) will be experiencing half the total potential or voltage .. .. if the resistance of the lower lamp is doubled the voltage across the lower lamp will be doubled.

S.17

the voltage reading will be less (than 4,5 v) with the bulbs in parallel because the current is less

I. Why is the current going to be less?

S. .. because it divides up (to the two separate parts)

Sometimes one cannot make out whether the confusion arises from the "volts" and current (since they are supplied from the battery) being thought of as behaving in a similar fashion or whether it is because basically students do not understand the nature of potential difference. There was definitely a strong indication that the electric circuit is thought of as a current system, and that voltage is then calculated from tthe current using Ohm's law. I will come back to these aspects in the next chapter.

For a considerable proportion of the students potential at a point and potential difference seem to be the same thing (since it is also measured in volts?); and it is normally lower on other side of the resistor, because the resistor consumes/dissipates the volts. At other times the potential is less because the kinetic energy of the charge carrying particles is less. "Voltage" is used to mean both potential and potential difference.

S. 1

the voltage reading (Figure 7 (a)) will be 4,5 v

I. If the voltmeter is put across the second lamp ??

S. it will still be 4,5 v

I. If put across both lamps ??

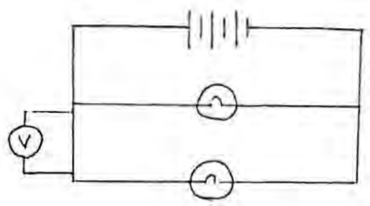
S. It will still be 4,5 v [Reason ?] .. .. it does not mean that when the current is flowing here that on coming out on the other side that the voltage has been lost

S. 6

I think that the voltage of this bulb is still 4,5 v [Figure 7(a)) second lamp] .. ..it will be 9,0 v across both lamps. It does not worry me that across both lamps there is now 9 v,

I. What is the reading of the voltmeter here? (Figure C)

Figure 7c



S. It will be 4,5 v

I. Are you not worried that there is no resistance between the two points?

S. No, I am not worried. There is a current here so there must be a voltage

S. 8

the reading is 4,5 v for the first lamp [Figure 7 (a)] and even for the second lamp .. ..

because the same current gets through the second lamp

[the voltage depends on and is preceeded by the current]

In the last example there was a hint that the emf or voltage etc is thought of as a constant "force" effective all around the circuit. Some students expected the "voltage" to be less for the second lamp when compared to that of the first lamp. This would be in agreement with the incorrect conception that the current (or charge) flows because it has enough force, electromotive force.

S.16

The potential difference across the first lamp
[Figure 7(a)] is 4,5 v .. ..
across the second lamp it is 2,25 v .. ..

Because the voltage will have dropped across
the first lamp and will be lower on the other side

I. Why is the voltage dropping ?

S. Because there is less current now..
because of this lamp

this lamp has taken some of the current, so it is
smaller now

When there is less current there is less voltage

S.18

The voltage will be 4,5 v .. .. that will be the
reading on the voltmeter

I. And across the second lamp ?

S. it will also be 4,5 v (Why will it be the same?)
Because it is connected to the same source

I. But a battery has high potential and
low potential side, Isnt ?
S. Eh! .. I am not sure, no .. .. Wait, .. I am making
a mistake
This reading [on right] will be less than 4,5 v

I. Why are you sure of this now?

Later on

S. I know .. .. this voltage will be less than that one
Even if the lamps have equal resistance

I. Can you tell me what they will be equal to?

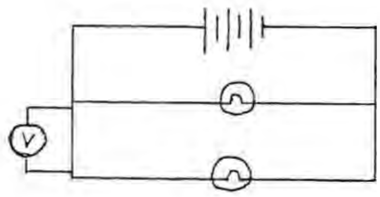
S. No. since I do not have enough details to calculate it.
[like what ?]
for example I do not know the resistance

I. Suppose the resistance of each lamp is 1 ohm
Can you tell me what the potential difference
would be in each case?

S. No, I dont know the current here, so I cannot
calculate the potential difference

There were indeed many instances which illustrated that potential difference is thought of as potential

In Figure 7 (c)



S. 8

since the voltmeter is connected to both lamps
the voltage will be 4,5/2 and 4,5/2 volt

S. 4

I dont think that it (the p d) will be zero
because some current is moving in this wire
it would not move here if there was no voltage

S.2

the reading will be below 4,5 v [Figure 7 (c)]

I. Why should it be less than?

S. Because the current has gone past this lamp
the current will be brought down by this lamp and
the voltage in the voltmeter will be less

S.17

the voltage will be 4,5 v.
The fact that there is no resistance in between them
(the points) makes no difference

S.12

It will be 4,5 v .. ..
It does not worry me that there is nothing between them.
This [lamp] is joined to the battery, that is
why the reading will be 4,5 v.

It must have voltage .. .. because it is connected

S. 1

the reading is 4,5 v

I. Are you not worried that there is no resistance
between the points?

S. In fact that is why I say that it will be 4,5 v
Because had there been a resistance there would be
a potential drop

There were many instances where students confused electric current with energy.

S. 7

the current supplied will remain constant as long as it

is the same battery

(even when the particular circumstances of the circuit

were altered)

I think that the root of the problems of students with electric circuits, electric current etc; is the handling of the concept of energy, its conservation etc. The students do not realise that the energy is input at the battery and that at the resistors and other circuit components this energy is output; and that energy is conserved in this process.

S. 1

as it (a coulomb of charge) passes through the battery
it gains 3 joules.. .. and on passing through
a resistor, it loses 1,5 joules.

S.16

the electrons gain kinetic energy as they pass
through the battery, lose kinetic energy on passing
through the resistor

In general the approach of students tends to be mechanistic and they think in terms of the actual mechanistic movement of charged particles. They think of electric current as the actual movement or flow of actual charged particles through a homogeneous medium resulting in the loss of kinetic energy when their original energy has been dissipated by the motion.

3.5.0 Conclusion:

The classical interview as used here has the disadvantage that it is usually very long. Students pause for very long moments. Since the thoughts extended have to be spontaneous, I could not always direct or pace students. If I interrupted often there was a real risk that I could influence the thinking through the suggestions and probing. I also did not want to do this in case what the student was talking about was actually connected. Often after a lengthy exposition the thoughts would actually get muddled up and would have to be cleared through further questioning. I found that some of the students were tentative and cautious in their explanations especially in the presence of somebody they supposed knew more about the things being discussed.

However the advantages far outweighed the disadvantages. Communication was far more effective in the interview, because it was direct and assisted through the use of diagrams, hands etc;. I could make sure to a closer degree, more than in the written responses, about what they really wanted to say. I could be more certain over the meanings that they were assigning to the words which they used; whether they were using a framework at all or whether they were just answering haphazardly.

The best questions to use as probes are those that encourage responses that are appropriate to the research interest, but which do not preclude those responses which though found appropriate when looked at retrospectively, were not considered by the researcher to be amongst the possible ones. There was thus an advantage in allowing a relaxed atmosphere during the interview to allow for relatively spontaneous responses from the students.

As it will become clear later on, such interviews have the potential to be used to find out whether the subjects are willing and able to follow considerations or notions induced by the interviewer. They may be viewed as micro-learning situations.

I was encouraged by the way students were prepared to discuss their views. I found them very relaxed and keen. After the interviews some said these had helped resolve some of their conceptual standpoints, and they felt relieved. Many more were eager for me to sort out the mess for them, to help them along the road towards better understanding. Often the initial interviews resulted in several follow-on sessions with the students through the year. I met some of these students three years afterwards when they were doing the teachers diploma, when I had an opportunity to supervise them, and they were at that stage very keen on developing suitable teaching strategies.

The investigation was carried out in the belief that students do have incorrect and inappropriate conceptions in the electricity section of the first year physics course. I have indeed established that most students do have conceptions about certain physical phenomena in electricity, which are not acceptable to the community of practising scientists. In that sense the investigation has been vindicated. The existence of alternative conceptions in the minds of students, which is now well established especially in the area of mechanics, has also manifested itself in this research.

In the chapter that follows I hope to highlight the students' unacceptable conceptions in greater detail, and to analyse more elaborately the alternative frameworks which I have identified and presented, using more extensively tabled student protocols. The models that students use will be examined in the context of researched and published alternative conceptions of students from other parts of the world. I will try to establish the more fundamental reasoning presented by students, the naive theories which students use to justify the incorrect conceptions. For example, in my experience, it is common for some students to say that "some electrons have been lost here" in order to explain how current is 'consumed' in the resistor. These explanations should be able to help instructors in correcting the wrong ideas. An attempt will also be made to illustrate how basic inappropriate conceptions are used by students to explain happenings in more complicated circuits, with disastrous consequences.

CHAPTER FOUR

ANALYSIS OF THE RESULTS:

4.1.0 General conceptual frameworks, attitudes and background of students:

The vast number of students involved in this study revealed some curious perspectives on the nature of science and scientific knowledge, which in some way or other are worth looking at closely. There were also certain philosophical outlooks on the nature of logic and explanation which manifested themselves directly and indirectly. My wisdom is that there is some merit in highlighting some of these outlooks as they define and influence the knowledge state of students, and would be bound to affect their performance at interviews of the nature that I conducted. The perspectives indicated above would also influence the scientific knowledge structure of the students interviewed.

4.1.1 The life-world outlook versus the scientific outlook:

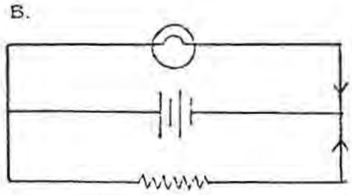
There was strong evidence in the interviews that these students operate in two knowledge systems; the one being that of scientific knowledge and the other that of life-world knowledge, without being aware of this. Life-world knowledge may be characterised, at this stage, as a system of beliefs and intuitions about physical phenomena, derived from extensive personal experience, which functions as a common-sense theory of the physical world and which the student uses to interpret his observations. A significant fraction of the students demonstrated clearly that they are not aware of the two domains of knowledge structure/systems and some made transitions from one to the other with impunity. Here follows examples of some typical responses:

(i)--the electrons will be tired by the time they
get to the battery. ..... they will not have
any (kinetic) energy

(ii) --the electrons .. when they get there (lamp),
they turn to light

(iii) --the electric current changes into light when
it reaches the lamp

(iv)



S. ... this circuit is not possible. The currents will
clash here at the junction.
In the end the bigger one (current) will overcome
(note the use of this word) the smaller one
and it (only) will pass through

Life-world knowledge is obtained by children as they grow up and sort out, voluntarily and otherwise, the physical phenomena that are, and happen around them. Life-world knowledge may be characterised as rather inconsistent and context bound and as cognitively irritable; it is not accountable to any specific elaborate theory. A response is just an answer; it may not mean anything beyond this. There is no need to explain why it is the correct answer, or that the answer given be subjected to further analysis. My findings were that very few young students of physics demand that their knowledge of the physical world become logically consistent. There was evidence that students never notice (or even think about it) that a second proposition they have used to explain in a physical situation is directly contradicted by one which they have used earlier to explain in another situation. The contradiction between this and the scientific laws is only too clear.

By its very nature scientific knowledge is completely decontextualised in the sense that it is not developed from any specific human oriented emotional or sentimental incident or context, and can thus be expressed in terms of 'kinetic energy' rather than running children, or fast and very fast moving objects, and not of 'tired' electrons. To the minds of most students, I have found, all fast moving objects are accelerating even though the velocity is constant; that the objects with a higher uniform velocity are accelerating faster than those with lower magnitude of velocity. In this sense these objects will have a higher value for acceleration, when it is actually only the speed which is higher.

Scientific knowledge constructs formalised symbolic concepts. By contrast, in life-world situations people operate more by analogy than by symbolic reasoning, and the tendency is to describe concepts by giving typical examples, rather than by explaining the concept.

This research has shown that conceptual frameworks rooted in life-world experience and common sense language are more general (common) than those appearing when a student is presented with a new situation and appeals to unforeseen analogies. I have to concede at this point though, that whilst the store of life-world knowledge, with any associated folklore and emotional overtones may not necessarily be science, it does generate tacit scientific knowledge.

Life-world knowledge is well socialised and secure. The meanings and outlooks thrive from continual use. In turn this gives them more security than scientific meanings, especially because the latter are confined to classroom situations of a few lectures a week. Meanings which are in daily use may not be easily obliterated by science lessons, however convincingly the latter may be presented, and are bound to compete in all pertinent spheres of academic activities especially during problem solving activities in physics. Simple circuit theory is particularly vulnerable to this because it uses common sense life-world words like energy, force, current, resistance, electricity 'use' turning it to light etc.

4.1.2 Coherence of scientific knowledge and unification of thought structures:

My assessment was that the students understand scientific knowledge to be a catalogue of small, not necessarily related, facts where there is no need for any coherence, or even overall consistency as a matter of fact. The mathematical formulas are used in an isolated, contextually (situation) bound fashion. In their approach to problem solving students think in terms of what formula to use or which is applicable. If presented with any numerical values they only think of putting these directly into a formula, or that these are probably related to each other simply by multiplication, division, addition etc, in order to get to the answer. Direct proportionality is very often automatically inferred in most physical relationships. There was sufficient evidence that science is taught as (or perceived by students to be) a set of rules according to which natural phenomena behave, a set of final solutions which are not necessarily coherent. The position that explanations of natural phenomena need not be coherent is a life-world outlook.

There is no thought of a fundamental principle being illustrated in a problem but only of a way of getting some answer; that science is like some kind of crossword puzzle the sole purpose of which is to get an answer even if this is by means of using some tricks;

that scientific knowledge is some bag of tricks where things happen if you are familiar with a particular trick or 'getting to the answer' strategy. The magic tricks are not necessarily arrived at or explained in any logical manner. Basically this may be interpreted as a life-world approach to solving problems. Unlike scientists students are not concerned with the need to have coherent and non contradictory theories and explanations to physical phenomena and their models. They will latch on to any one of a number of possible explanations which are reasonable from their restricted outlook.

Examples:

I. Can you tell me how much current flows through this resistor?
S1. I dont know what formula to use here

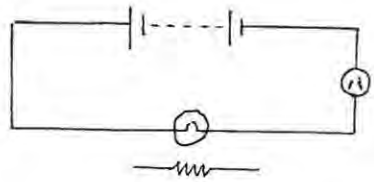
I. In what way will science increase?
can you give an example?
S2. .. the increase of science may be caused by (for example) the changing weather patterns that we now have (observed) in Port Elizabeth. They will have to rewrite the laws of Geography and put in new information as to the ways (various ways) that it actually happens

S3. Our difficulty as students is that ......
When we read we dont go deep, we just look how to solve the problem without an understanding of what is going

4.1.3 Attributing too much to visible causal agents:

Students have difficulty with the kinds of abstract reasoning which scientists are capable of. They tend to view things from a self-centred or human-centred point of view, hence the 'tired electrons' mentioned earlier.

For example:



S. ....If there is a lamp here, the current would be less on the other side ...but if there is a resistor it will be the same....
I. WHY ?
S. ..because current is lost in the lamp
I What about in the resistor?. I thought you said earlier that the current will be less on the other side of the resistor as well
S. The resistor just makes the current less, ... because it makes the speed of the current less [reduces the speed of the electrons] -- well less current is lost in the resistor anyway. You see there is no light coming out there [in resistor], so there must be less current spent there than in the lamp

More energy is given off in the lamp than in a resistor (of equal resistance value to the lamp) purely because the student can see something (light) coming off the lamp, when there is no obvious evidence that even heat comes off the regular resistor. This is an example of the attitude that non-observables do not exist. They look at electrical components in a circuit only in terms of usefulness, and consider only those entities and constructs that follow from everyday experience.

Examples:

S1. .. the current comes from the battery.
It is stored in the battery.
the current is there .. in the unconnected battery

S2. .. what is the purpose of the resistance in the circuit if it does not use electricity?

The presence of batteries, lamps etc in simple electrical circuits, then makes it tempting to attribute too much of the observed behaviour to these obvious causal agents, and too little to the action of the charge itself. Hence the students conclude that what now 'is' in the connected circuit must come from the battery, including the electrons.

S. ....the current comes from the battery

It was stored there

Also, in spite of the definition of electricity as the rate of movement of charge students prefer to think of it as the movement of electrons (charged particles) purely because they (the electrons) are particles which can be imagined to exist. They will even think of current as the movement of protons. I have refered to this view in the literature review as the atomistic view.

S. ...the cell loses energy to eh!! ..Andithi (isn't it?),
this energy is given to the protons as kinetic energy.
When the protons gain the kinetic energy they are
able to move from place to place in the circuit

Since charge in their minds is purely an abstract concept they do not think in terms of it. This certainly influences them to think in terms of the kinetic energy of electrons as an indication of the magnitude of current at a point, presumably kinetic energy is an observable form of energy as opposed to deeply conceptual forms like electrical potential energy. I will come back to this latter point.

4.1.4 Role played by language and its metaphor and linguistic transfer:

I have found students unable to distinguish between force and energy conceptually. In the 'unscientific' life world context these probably have the same meaning. One has to admit that there is a possibility of confusion caused by the wrong use of the word electromotive "force" implying force, for energy per unit charge supplied from the battery. This word makes one suspect that even scientists before did not separate conceptually between force and energy in this context. One can see no good reason why this particular concept term has been left in this form for so long; it is certainly misleading.

Examples:

S1. the electrons will move around the circuit because they have a force (the electromotive force)

S2. they (electrons) will lose some force when they pass the resistance

S3. the electrons are given the force by the battery (the electromotive force)

It is not clear at this stage how far this idea is reinforced by the thought of 'charged' particles being involved here. The charged particles have been interpreted by some to mean the particles are "filled up" with energy (force?) or energised. The conceptualisation here in any case is quite distinct and separate from the other simplistic theory that electrons are given an initial push at the negative electrode of the battery and proceed along the rest of the circuit because they possess enough kinetic energy (from the initial push) to do so.

Also it was evident that there is a problem with language and linguistic transfer. A significant number of school textbook use the phrase "current is supplied by the battery". My experience is that it is difficult for the student, for whom English is a second language, to understand in what sense electric current is supplied by the battery if the current is not less on the other side of the lamp to which it was supplied. The role played by language, and its metaphor, should not be underestimated as it influences the conceptualisation of students. It is to be expected that the students will have already acquired a whole repertoire of meanings for common words like heat, light, electricity, conservation, energy, work, the verb 'supply' etc, by the time they enter university. These words, used in ordinary conversation, will have so called common sense meanings which are not precisely (scientifically) defined in the life-world knowledge structures of the students.

It is a common practice for scientists to take words like energy and work from common sense language and use them in scientific language, extend their meanings as they confine and restrict them to special meanings in specific contexts, and as part of scientific jargon. Teachers of science often do not explain carefully the special meanings of the words. In sections of theoretical physics experts refer to sub-nuclear particles called quarks which not only have spin and flavour but also colour and even charm. The problem of scientific language is often compounded particularly for those students who are taught in English and whose mother tongue is not that language. It is possible that for some of them the very common sense meanings of words, are likely to have been acquired from English language classroom activities and may, in themselves, remain artificial/academic classroom acquired meanings / knowledge.

Example:

A common misconception in the area of Mechanics for students is that a body continues in a state of motion because it contains a force, imparted to it earlier; that the inside force is consumed by the motion (the body will come to a stop when the force inside it is finished) or is dissipated by resistive objects. Resistance opposes an applied force or consumes the Impetus (F=mv) of a moving object. In electricity we find that students believe that electrical resistance consumes the electromotive 'force' contained in the electrons as they move through the circuit.

4.1.5 Reluctance or inability to extract / separate system from environment:

A large number of difficulties experienced by students seem to be closely related to a lack of recognition and acceptance of certain values which scientists, particularly physicists, take for granted and hold sacred. These values include public objectivity, prediction, quantification, broad applicability, and the assumption that it is possible for a representation of A to capture the essential features of A. Physics students are often reluctant to accept a distinct separation of system and environment, and are unable to follow the notions of cause and effect used by scientists. Even at the conscious level they are unable to separate a system from its environment and to model it.

Significantly large numbers of them are confused by the use of models in the typifying of physical phenomena, the idealising and extraction of these models from life-world situations. Their difficulties arise from taking the reality as it happens in the life-world situation and modelling scientific laws and theories from it; without taking the system out or identifying any extraneous features or influences that are not pertinent. Science through experiment as a basis (if laboratory oriented and controlled) is O K, as long as casual informal findings in ordinary life-experiences are not necessarily assumed to be science, especially at school level. **For example:**

A student might casually observe in nature that when a body has been given an initial push, on a horizontal plane, it eventually comes to rest. This student may then assume that the body was given a "force" and continued moving for as long as it still had the force. His scientific knowledge may conveniently be that " bodies continue to move because they have a force (contain a force inside them). I have given examples in this already where students have said that an electron moves around a circuit because of the force given to it by the battery.

Some students think of nature and natural laws / physical phenomena as completely and absolutely defined by the laws which physics theories have evolved to the extent that the laws of physics prescribe on natural behaviour. If nature appears not to obey these laws, [for example the body described in the last paragraph does not go on for ever in a straight line.] the students are confused. The action of friction forces is normally discussed in detail much later at university.

On the contrary scientists realise that the physics (the theories which they evolve) is that of the models created by the scientists and that these models only approximate reality in the physicists understanding of it; that in the final analysis reality is itself and we are unable to change its natural / fundamental tendencies.

Also the students tend to get trapped in their own models or those prescribed by their teachers. For example, the water model of current:-

Because a fast 'rushing' current of water implies a large (high magnitude) current of water, students have deduced the meaning here that if the speed of the charge carriers is apparently higher at a point in a series circuit, then by implication the electric current is necessarily larger at that point. As a result of this it becomes difficult to accept that the current passing through two resistors in series (a small one and a large one), could be equal. They are inclined to think that the electric current will be faster (bigger) in the resistor made from thinner wire even if the two resistors are in series.

In most of these cases, students tend to fumble through a lack of a theoretical base and fall back on their own theories, newly constructed from personal experience. This exercise is often not fruitful because they make incorrect conclusions.

4.1.6 Recapitulation of historically earlier "theories":

A tendency has also been found for students to recapitulate historically earlier scientific theories. I presume this is because they go through the same life experiences and thought processes as the age old scientists who had propounded these theories. Evidence of this is the abundance in students' minds of the so called Aristotelian ideas, the medieval Impetus theory and vitalistic conceptions of energy. There were examples of students arguing that the electrons are given an initial 'push' by the battery terminal and continue through the electric circuit elements because they still have sufficient force in them (from electromotive 'force').

4.1.7 Inability to reason effectively:

I found that the thinking of students is particularly hampered by some major difficulties in the theory of current electricity. By the nature of it the theory fails to provide students with the ability to reason effectively about electric circuits. One difficulty is that there is an enormous perceptual difference between circuit phenomena and the macroscopic electrostatic experiments that are normally employed to generate fundamental concepts. This makes it difficult for students to imagine circuit behaviour as deriving from electrostatic experiments within an invisible system of mobile electric charge. I think that they would probably prefer to actually see the charge moving; although this might influence them to think incorrectly in terms of the kinetic energy of the charge.

An easily observable/perceptible phenomenon for most students is electric shock whether it be from a regular electric circuit or from a natural occurrence like lightning. The unseen current 'shocks' on passing through the body and usually operates in an unpredictable way, since nobody will normally voluntarily subject themselves to shock anyway. Lightning has the same name as electricity, as current, (not necessarily implying current flow) in most African languages in the sub-continent; its behaviour is not predictable, may in fact be inexplicable. I found a significant number of students affected by this (about 35%). These students did not expect the flow or 'movement' of current in the circuit to be predictable or to follow any predeterminable behaviour; that we could not predict with any certainty whether there would be more or less current in any circuit loop. This was particularly reinforced by the experiences of students in the laboratory.

Evidence:

I. Is it there (the current) in this circuit? (hiding)
S.1 I cant say ....we would have to measure it first to know if it is there..
I. How??
S.1 ..... by using an ammeter

S.2. ...the behaviour of electricity (lightning) is unpredictable ....and hence experiments in the lab cannot be predicted ....
sometimes you are just standing there or just connecting... and there is a spark or some form of lightning for no reason ......

or the wire suddenly becomes red hot and burns

S.3 ...I have always believed that it behaves in a way
that I cannot understand. Hence I am afraid of
working with it.....
It could shock you whilst you are standing there ..
You cannot see it ..
I would not touch the connections because
'electricity' might be (lurking) there somewhere.
(like a snake waiting to pounce on you).

This latter idea may be nurtured by the misconception that electric current is a 'thing' that moves from this point to that point in a circuit instead of being a rate of flow of charge at a point.

There is a possibility that students' thinking in this direction may be influenced by a belief prevalent in some cultures that science is synonymous with some kind of magic and magic tricks. There is a lot of folklore around electricity and lightning. For example there is a belief that if you do not like a certain person, you can go to those that know [ooSiyazi = witchdoctors] and ask them to send lightning to strike and kill your enemy, even on a cloudless day, let alone a rainy one. Magic works at certain times, with some people, and there is no pressing urgency to search for reasons why, because that is the nature of magic.

As indicated earlier on in this study, people with "unscientific" minds do not bother to try and explain why things happen in a certain way and not in another. They would probably worry about this only if it 'threatened' them in some way; and again could quite easily resort to "it was created by GOD to behave like that". This is a very popular viewpoint amongst some people. Having said all this we have to admit that, in examining alternatives in the nature of knowledge and psychological development, we will find that learning will occur only if the learner views the knowledge as having personal relevance, otherwise it will/may be done by rote. If the circumstances actually threaten urgently, psychologically or otherwise (has to know in order to survive eg. pass examinations), he may accept any (even non-logical) explanation as long as it covers all ground even if haphazardly.

4.1.8 Inability to think logically, to think operationally:

I also observed that physics undergraduates are often at a loss even to know whether they are in possession of an explanation or answer. Quite often the answer that I would get was the result of mere recall or an attempt to do so, of what the previous teacher, or some textbook, had said. Some students were completely unaware that arguments in physics are informed by logic and there was evidence of inability (even unwillingness) to subject physical arguments to logical scrutiny, or to see that logically defective statements cannot be valid. Consequently they were unable to defend their own explanations or to develop on them.

The evidence is that the teacher is generally accepted as knowledgable, some kind of guru in the society, and whatever he said 'it was', was accepted and for that reason not subjected to further scrutiny. The last point is probably associated to the socio-cultural background of the students. The attitude was that every situation has a unique explanation which can always be got from those who already know without subjecting the explanation given to any further scrutiny. If the interviewer insisted, there were difficulties in getting any sense or overall logic in the explanations given.

Examples:

S. ...frankly I dont know .....I think I am confused now

S. I dont understand what you are asking ..

S. ...I do not remember what my teacher said (about this)

Needless to say this results in students thinking of science as little bits of this and that, which have got separate, unique explanations. This also encourages learning by rote. The tentative role of science is also challenged in this approach. More recently I had opportunity to interview some postgraduate teaching diploma students (H.E.D class of 1985 at Fort Hare) and more than 60% of them were not ever told by their teachers about the tentative nature of scientific knowledge and more than 90% had never thought about it anyway and would not normally try to indicate it to pupils they would teach.

4.1.9 Influence of age, intellectual maturity and social values:

This point is very much linked with the last one. Many, if not most, fail to examine evidence critically, to establish a line of reasoning, and to reach a conclusion or interpretation. The effort required often leads to impatience, frustration and even antagonism. They will expect the teacher to tell them the "correct answer" rather than to establish themselves a line of reasoning leading to the best interpretation. The reasons for this lie deep and may well be nurtured by fundamental misconceptions on the central role of evidence and reasoning in science.

There are other thoughts about this particular problem. Students initially hold interesting views about learning and knowledge which may be said to be dependent on or to be influenced by age, intellectual maturity and social values. The thesis in this connection is that of a development scheme which proposes that college students gradually change the way they view learning, knowledge etc, as they move through the first few years of university [Perry 1970, Allen 1987]. In the initial stages of intellectual development, students hold on to the dualistic views of absolute right-wrong and good-bad. Authority is viewed as the ultimate and the immediate source of decisions regarding right versus wrong, and good versus bad. The authority in this case may be any source that the student accepts, for example his teacher, parent or textbook. Whatever the choice, the authority of the chosen source is absolute.

------ it must be true if Newton said it was so--

Later on, as the intellectual development proceeds, more pluralistic views will be adopted by the student, where knowledge and values are perceived as relative. Moreover, at this stage, the student perceives that validity is determined by the coherence and internal consistency of the interpretation as well as the available evidence. Compare this with ---'according to the textbook' or 'I can not remember what my teacher said the answer was here'.

Within this scheme students at different stages of development would be likely to hold drastically different views of science. If the student was at an earlier stage it would never occur to him that he/she should (or even could) interpret data and observations or draw conclusions from experiments. Decision making would be looked upon as a puzzling or incomprehensible process without an authority to provide the "right" answer. It was evident that many students do not realise that if their study is to be productive, a large portion of it must be directed towards understanding the lines of reasoning relating to evidence and conclusions, rather than merely towards memorising those conclusions.

S. ...I think, Sir, that the problem is that we dont think
deep enough about these things....when we were at school
we just try to remember what the teacher says.

It is clear that most of the aspects discussed above overlap a great deal, are very much related, and that they are much influenced by life world outlooks and circumstances. The issue of how these are generated and influenced by direct schooling are worth looking at closely. Some of these perspectives will hopefully become even clearer in the analysis that follows.

4.2. Specific Misconceptions and Inappropriate Conceptions:

4.2.1 Concepts of Current Flow :

There is broad consensus on the nature of electric current, and models of current, amongst the majority of the students who were involved in this research effort. Whether a particular model turns out to be the most appropriate one or not is another matter.

The most general conception seems to be that electrons are generated inside the battery, positioned at the negative pole and pass down the circuit as electric current attracted by the positive pole, and eventually in some cases neutralise the charge on it. Electric current does not flow through the battery, as this would imply that charge flows inside the battery, which in turn would mean that electrons flow inside the battery between the terminals. One reason why the electrons do not pass in the reverse direction inside the battery is that the two electrodes are insulated from each other; another is because the negative electrode would not attract the electrons [inside the battery] towards itself anyway [fair enough]. The arguments given above indicate why it is very important in the students' model that electric current must not pass through the battery. Indeed in more than 75% of the cases tested the overiding conception was that electric current does not pass through the battery.

One mechanism of the flow of electrons [= flow of current] in the outside circuit, was that they are repelled by the negative pole and also in themselves individually push and repel each other along the circuit wires towards the positive side of the battery.

> " -- ...this electron pushes the one next to it, which then pushes the one next to it, and so on "

Also, the electrons flow because they have just got energy from the battery.

A more appropriate view is that the electric current flows through all circuit components including the battery, the flow being maintained through some mechanism in the battery source.

(i) Students understand electric current to be the flow of charged particles, preferably the flow of electrons, but sometimes that of protons. Of relevance here is that they do not generally conceive of electric current as a rate of flow, but rather as a flow through space and time. Only about 10% of all those interviewed (N=101) voluntarily suggested that electric current is a rate of movement/passage of charge (charged particles), and even a fewer number as a rate of movement past a point (cross-sectional area) in space and time. In the majority of cases in point here the rate of flow is based only on the speed with which the charged particles (not charges) flow in space; the faster the charged particles move the more the current in that space; and not on the quantity of charge flowing past a point in unit time. Hence the whole basis of a large current relies only on faster moving electrons and never on more electrons (or charge) passing through a point. Also, electric current is rather conceived as setting out from the negative side and proceeding in space and time to the positive side of the battery, followed by another current (charged particles pocket ?) in very close (indistinguishably close) proximity to the first one, and so on, continuously in time. This may be deduced from statements by students :

that current [before the resistor] is still at a high speed because it has not passed the resistor, whereas the current on this side [after resistor] has a low speed because it has already passed the resistor

It seems that each current loses its speed as it proceeds along the circuit in a time dependent fashion.

(ii) The concept of current flow seemed to give a lot of problems to students. Their approach is inclined to be macroscopic and tends to describe electric current as a flow of charged particles, through a homogeneous medium, very much like water in pipes, resulting in a loss of energy, which to their minds must always be kinetic energy. Again here one imagines that they can relate easily to flowing particles than to flowing charge carried by the very particles.

(iii) I also found that flow to most students does not only imply in a specific direction at a point, but rather more emphatically a flow from one point to another (eg. from the positive to negative side of battery). I think that school teachers are to be blamed for part of the problem for this, for not pointing out that it is the charge which has to be considered here, and not necessarily the particles, and that -from positive to negative- here basically indicates a direction [orientation] of current and not a point to point flow.

The atomic theory of metallic conduction, utilised in many standard introductory physics textbooks, and in which the electron loses some of its kinetic energy, at each of the many collisions with a lattice ion, does not take root, neither does the idea of drift velocity of the electrons. Neither of these gives any reassurance because of their approach using electrical potential energy, particularly electric fields etc. I suggest that these ideas must be consciously taught as acceptable science. Appropriate scientific conceptual models need to be formally introduced and explained.

Many of the students that I have met speak of

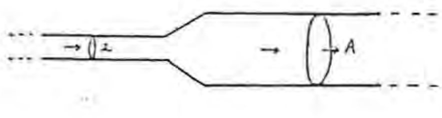
--.....'the current comes and stops here' S.19.

Current as a rate of passage of charge ($I=dQ/dt$) to their minds is only a superficial definition and does not take root.

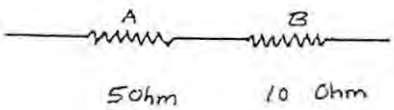
(iv) My impression is that even the so called 'water model' introduced earlier in school from teachers, books etc, had not been used to maximum benefit. What is quickly established from this is an equivalence between electric current and an amount of water [a specific volume element of water]; instead of between current and an amount of water per sec [eg cubic metres per sec or kg per sec]. It seems that the idea that takes on is that since the water starts from somewhere (tap) and goes elsewhere, then the current [equated with water] must start or come from the battery -- which is unfortunately not correct.

Students do not have close familiarity conceptually with pressure, its generation and build up and related phenomena, in water pumps and taps. As we have mentioned earlier, students have a problem in realising that physicists create and use models of the reality and that basically the theory (Physics) is that of the extracted model. The students associate the model (the theory) naively with the life-world children's science, with a crude model from their personal perceptions of experience with phenomena in the environment.

(v) The pattern of thinking is that faster moving electrons, even if moving through a narrower channel imply a higher value of current at that point. For the average student (48%), there is more current through A than in B (see figure below) where the electrons are slower.



Figure



(vi) The results give clear evidence that students do not fully understand the link between current and flow, and 44% were happy to say there is a current in the unconnected battery. These students believe that although there may be current in the battery it is not flowing, that it actually starts out from there.

S.1 "there is current in the battery, although the battery is unconnected .. .. even though it (current) is in a state of rest"

S.6 "....there is a current, but it is not flowing...

S.23 "there is a stationary current in the battery although the battery is not connected
I. How do you know ?
S. .. it is difficult to know (prove) that there is a current in the battery unless you test it. ....
I. How?
S ...by connecting an ammeter to the battery .....since I have now tested it, .. . I can say that there is a current.. --... the current is stored here in it.

This makes one wonder what conception of current the students have if they are even prepared to say that it (current) is stationary. Also, to many students flow suggests movement from one point to another and does not necessarily include continuous flow past a certain point in time. It is also probable that they are wrestling with the whole issue of energy transfer in the battery.

4.2.2 Models of Current Flow :

In dealing with most inappropriate conceptions of current the instructor has to be constantly mindful that most students have basically inherited from their background the fluid metaphor intuition of current [Johsua and Dupin 1987]; namely, a model of a flowing current which is at once a fluid of matter and a fluid of energy. The problem of the student [as he sees it] is 'how to explain' that the [material] fluid conserves itself and, at the same time, as energy [the fluid] 'exhausts' itself on passing through a resistor as evidenced by the light, heat coming off the bulb and by the wearing down of the battery in time.

There is very strong evidence that students think of electric current as synonymous with energy -electrical energy - and this would explain, in part to their minds, why "current" is resident in the battery; flows from one point to another when the switch is on, in order to take energy to the resistor (lamp) where the energy is 'turned into light' etc. I have discussed this view at length in the literature review and will come back to it later.

A number of models of direct current emerged.

(1) One of these is associated with the idea that the battery is the source of current in the electrical system; that this current is of a constant value. This is the "current precedes voltage" model. In this model "voltage" is supposed to occur (via V=IR) because there is

a current in the circuit; the current being supplied by the battery. Clearly in this model, current is very much confused with the energy quantities of power and electromotive force, 'voltage' etc. It does indicate that current is thought of as a form of energy stored (note that not necessarily generated / maintained through a potential difference by some continuous chemical process) in the battery. Also in this model students treat current as naturally assuming a constant value, and as necessarily unaffected by changes in the outside circuit, for example the change of resistance. It may be generally referred to as the "constant current model". There is sufficient evidence of this misconception from the earlier part where current is thought to be stored in the battery.

S.23 .....the current starts to flow from the battery
and goes to the lamp, and then the bulb (lamp) glows..
--otherwise the current is stored in the battery.

S.2 ...I think that the current is stored in the battery...so
that when the bulb is connected it will light.....If there
is no electric current in the batteries we would not be
using them [batteries] to get light in this bulb.

Student: Bongiwe

S. ..you see sir, I can say this thing is like this. ..
The current starts from the battery

I. How do you know how much of it is there?

S. .. it depends how much the emf of the battery is..
then you get what the electric current is.
You see, it depends on how much negative this side is.
(How?) ..well the larger the emf the larger the
current coming out will be

I. I mean, how do you get to know the exact value of the current

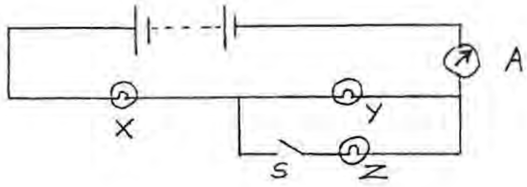
S. .. .. it will be there in any case.. you can use an ammeter
to know what it is (How?) .. by connecting it to the battery.

I. are the resistances in the circuit used in any way in
making out how much current a battery gives?

S. ..Well, you can use the internal resistance at least..
. no . .. not the ones in the main circuit. (Why not?) You see,
that is where the current is going to go (afterwards)

The clearest of evidence that a battery is considered a source of constant current was around the following example:

Figure



I. What do you think happens to the brightness of these lamps [X and Y] when the switch S is closed

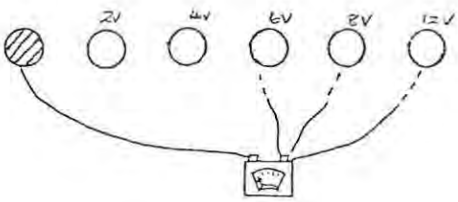
S. 7 if the second lamp Z is put in parallel with the Y there should be no difference in the brightness of X .

(Why?)

because the same (quantity) current will be passing from the battery.
[lamps] Y and Z will have to share the remaining current equally, after X has taken its part

I have witnessed a number of times generations of students in their third and final year of study making a similar mistake as well, when doing practical work:-

In the laboratory, on the working benches, there are points where power can be tapped off (emf source marked: see Figure below)



Several times I have caught the students trying to find, by connecting an ammeter directly in series with a source, from which terminals (+2; +4 or +8 volts etc;) they could get most 'suitable' current with the arrangement as shown above.

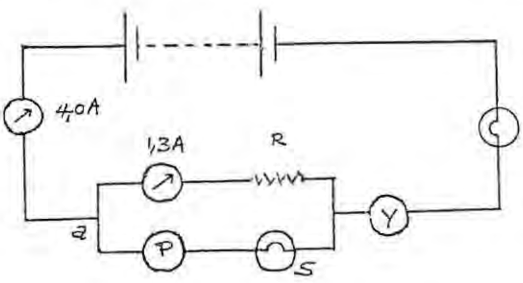
[suitable =a specific value before hand which may be used with one of the components of the circuit. [In this case a Hall Effect p-type semiconductor specimen in which a maximum value of current (order of milliamps) is indicated]. As a rule these sources will indicate much larger values of current and it is always hard to convince them that a resistance in the circuit could solve the problem.

Cohen et al [1982] have also identified instances of this tendency amongst students in Israel.

Here follows a scenario in which a student reaches the wrong conclusions from assuming that the current is primary and uses the "K.E. of electrons is proportional to current" framework.

Student : I G K

The following diagram was considered



Figure

I. What is the reading of the current in the ammeter P ?
S. I think that the current will be 1,3 A
I. Why?
S. ...because they (the meters reading 1,3 A and P) are connected at the same point, and the current divides at this point [a].

I. Why should the current be the same in the parallel parts ?

S. ..because the current at this point has a certain speed and when it divides it will have a similar speed in both directions.
I. What about the potential difference? ....

S. ..it does not worry me that the p.d.s 'of' R may not be equal to that of lamp S

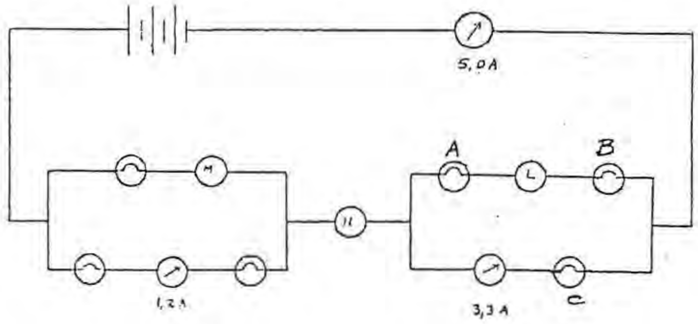
In many instances it became obvious that the students are prepared to sacrifice potential difference, and will conclude that it is in fact the p.d. that is consumed by the resistance via the use of Ohm's Law. I will discuss this point later and separately. In fact logically the idea discussed above leads to the p.d. dividing at the junction as well and then V=IR is applied to the separate arms of the circuit. The interpretation here is that the current sets out from the battery expressed in terms of energy (often kinetic) which dissipates along the circuit. 'Voltage' at any point where the current [and R] is known may be determined using V=IR.

Here follows another protocol in which the current divides equally at the junction because it (the current) arrives with the same speed at the junction, and therefore should be equal in either branch.
In this example is manifest an additional perception about current (or current model) -the consumption of current by a resistor. There may be other inappropriate conceptions as well in the following protocols but these will be discussed more specifically at a later stage.

Student: tyana:

Using the Figure shown below

and using the current flowing from negative electrode convention



S. ....the current in L will be 3.3 Amps

I. WHY ?

S. ..the light in this one (C) will be more (meaning brighter) than the light in these two (lamps A and B) because these two share the same current (3.3 A).
The currents in these lamps (A and B), .. they must (their sum) give 3.3 A
This lamp [A] will not be as bright as that one [B]

I. What is the current in A then?

S. I dont know .....since I dont know the potential difference in A and R the resistance of A

What we note from this interview is that at the branch off the current will be total 3.3 A on either side, even if 3.3 + 3.3 gives a value bigger than the 5.0 Amperes measured earlier in the circuit.

Student: Qhani

uses the current is flowing from negative electrode current convention

S ...The current in L will be 3,3 A ..when the current divides into equal halves and goes over the one lamp. .. .even on the other side it does the same, so it will also be 3,3 A

I. If L is in the place of first lamp (B) ?

S. The current will be above 3,3 A

I. But this means that the current does not divide half / half, according to you (as you said before), at the junction ?

S. It is this (value) because it (current) has not passed this resistor (lamp B) .. .. You see Sir, on the other (lower) side, it is 3,3 Amps after passing this lamp [C]

I But this would make these two currents [3,3 A + 3,3 A] larger than that 5,0 A reading. Are you happy with that?

S. .. .. Well .. .. Eh .. maybe this 5,0 A. .. I can say, it's a mistake. It must be bigger.

I. If I tell you its not a mistake?

S. Well I dont know then

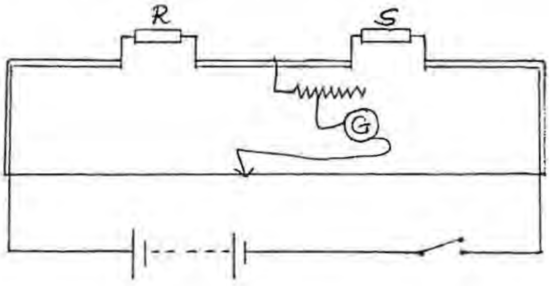
Later the suggestion was made that the current could be even 5,0 A to the right of B and also C, after all it arrives at the junction with the same speed.

I. If I put L in the place of the second lamp [A] ?

S. It [the reading on L] will be less than 3,3 A .. .. - .. .. in [ammeter] N it will be a little more than 3,3 A because these [currents, from the parallel parts] have now combined

The sequential time dependent model which was identified by Shipstone [1984] (introduced in the next paragraph) is clearly evident here as well.

(2) In the second model the current flows in one direction around the circuit becoming gradually weakened as it goes, so that later components 'receive' less current. This model becomes evident in many instances when students perform physics practicals, especially in those laboratory activities that involve the use of a galvanometer eg. potentiometer and bridge circuits.



The students are forever set to put the large resistance, to "protect the galvanometer", in a position in the circuit such that the current should first get to the resistance before it gets to the galvanometer. They argue against putting the resistance in series with, but just after the galvanometer, because the large current would then get to the galvanometer first and would damage the galvanometer; whereas if the resistance was before, the current could actually be reduced by the resistance. As an instructor I come into the picture when they want to know which way the current is actually flowing, since at school they had been told it is the flow of electrons and here we say it flows from higher potential to lower.

In this model of the current only the variable resistor put "before" the lamp (see Figure 1 below) will have an effect on the brightness of the lamp.

Figure 1

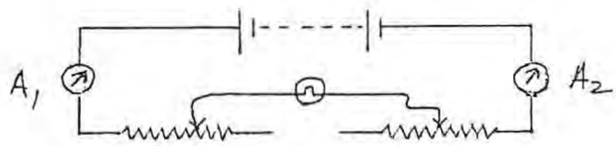
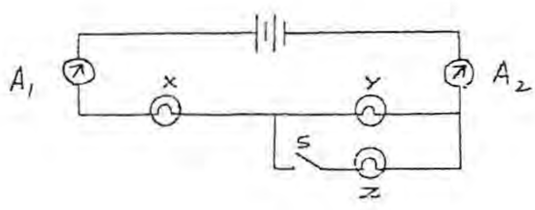


Figure 11



Student: qhani:

Refer to Figure 11

I. Does the current in any way depend on what resistors are actually put into the circuit?
S. No! .. the distribution of the current does not depend on the value of the resistors

I. What does it depend on ?
S. .. .. on the battery .. .. .. its emf .. ..

This argument also confirms the previous model of current as a constant as supplied by the battery.

Switch S in the open position:

S. .. in the series case (lamps X and Y in series) the voltmeter reading will be less in the second lamp (Y) .... because the current is now <u>less</u> than that through the first lamp (X)

This also confirms indirectly that the potential difference (or voltage) is dependent on the value of the current by way of the use of $V = I R$.

I. Why is the current going to be less than in the first lamp ?
S. ....because the first lamp (X) takes it own share .. .. a large share of the current

I. Why a large share?

S. ....because it is nearer to the battery and the potential difference is higher there, because that lamp is nearer to the battery

I. How do you get the current through X (the first lamp) then ?

S. ...using V=IR ....

I. Will the lamps be of equal brightness??
S .....No''' ... the lamps will not have the same brightness

Fredette and Lochhead [1980] also mention a similar model which relates to the proximity of the one lamp to the 'source'. One notices here also the confusion between the potential and potential difference. They are treated as the same because they are both measured in volts. Perhaps the following extract illustrates the fundamental reasoning behind this model:- viz that current is proportional to the speed with which the electrons (or charges or charge carrier particles) are moving inside the wire.

S. ... now X will be brighter than Y because the speed with which the current enters Y is not the same as that with which it enters X ...it is less

In the example that follows the student uses the same kinds of argument in spite of the fact that he uses the conventional 'positive charge flow' model for current ie. from the positive to the negative of the battery. It perhaps also illustrates the reason why (in students thinking) current must be lost at each lamp.

<u>Student: pepa:</u>
Refers to the same figure as above.

--Current sets out from the positive of the battery convention

S. Some of the current is taken up in the lamp here (X) . It (lamp) converts it (current) into energy with which it is going to give up light..........

... Y ....and Z will be brighter than X .... because they are nearer to the source

.. Y and Z will be of same brightness. ...Y and Z share the current first, and X will get a current which is already less .....

I. WHY less?..

S. .. it [the current] will have been taken up by these resistors (Y and Z)

(I will use this protocol in the next model of current as well)

We have the impression that this model is enhanced by the idea of loss of kinetic energy by the electrons at a resistor; in other words by the concept of current flow that the students hold. Here follows another example that further illustrates this. The current is less because its speed is less than when it reached the first lamp.

Student: Nase

(elsewhere in another context)

....the speed will be the same here .. .. hence there is no potential difference between these points

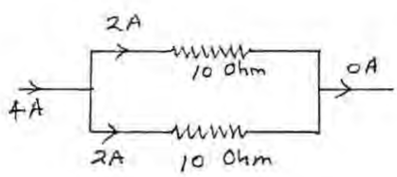
S. ..if the switch S is open (Figure 11 above) ...(lamp) X will be brighter than Y.. .because of the speed with which the current (speed of the current?) enters Y is not the same speed with which the current enters X .

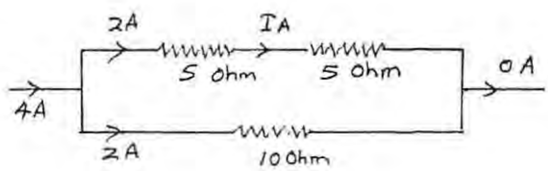
In the model, also diagnosed by Shipstone [1982], the current is influenced, in turn, by each circuit element that it encounters, as it progresses around the circuit. If a change is made at a particular point, then current is influenced by the change only when it reaches that point, and not before. This model is readily visualised, unlike the accepted and more appropriate view of a circuit as an interactive system. Authors have referred to it variously as the time -dependent model of current flow [Riley et al 1981] and as the sequential model [Shipstone 1982], since a sequence of events is believed to occur as current flows along a circuit. The spatial factors are at least as important as temporal factors in this model.

This inappropriate conception represents a fundamental misunderstanding of circuits, and is clearly of major importance because of its high incidence (75% in my case). Other workers have also reported a high incidence and persistence of it even amongst postgraduate students [Shipstone 1982].

In the samples of students tested, this model was particularly prevalent and they seemed particularly emphatic in using it when tackling more sophisticated circuits in problem-solving. It hinders the conceptual understanding of Kirchhoff's rules, and also the application of these principles for the conservation of current and voltage. According to the sequence model, when current 'reaches' a resistor the effect of that must be to alter the current strength so that the current leaving the resistor differs from that entering. Thus the error of failing to conserve the current is a consequence of the sequential model.

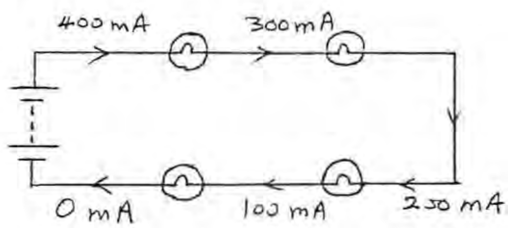
(3) In the third model of current, the current is used in each component of the circuit. It is important to note here that whilst the current is shared proportionately via the use of Ohm's Law in the model, there is no conservation of the current. The model is tied up to the intuitive source - consumer view of electricity. The current goes to the point where it is consumed and not beyond. I have chosen to list this as a separate model to the one before for this reason. I believe that the previous model is more tied up conceptually with the idea that current is lost because the charged particles (or charges) lose kinetic energy on passing through a resistor rather than the source- consumer view of electricity. In the source-consumer particular model the current is used up as it flows through a circuit, in the sense that electric current is energy.





The electricity (current) flows to that point to be used there.

This 'use' of current by circuit elements is associated to the life-world meanings of the "use" of electricity mentioned earlier on in the chapter; more directly to the idea that electrical current is energy -electrical energy. Later on we will discuss how this 'electric current = energy' misconception permeates the whole of students' views. The important thing to remember about the model being discussed is that although the current is shared, it is not conserved. In fact in some examples of this misconception charge itself is not conserved, thus as 'electricity turns into light' some of the charges (or charge) change into light energy. In this model current goes to a particular point and is used there whereas in the sequential model discussed earlier the current was reduced in sequence. Even when the resistors in the circuit are arranged differently it is expected that the current 'used' by each resistor is still the same as before. Students use the "sharing of current" misconception to explain "successfully" how equivalent lamps arranged in series may have equal brightness.



The protocols of Qhani, Nase, Tyana etc, listed earlier in the chapter indicated quite clearly that students think of current as being used by each part of the circuit. Here follow some short extracts from other interviews:

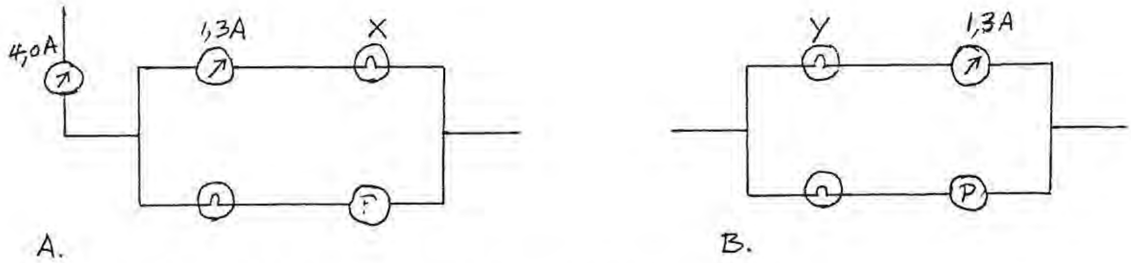
Student: Rama J:

Figure on page 125?

S. I cannot determine the current in L ....
-.. .. because I dont know how much current is used by
this bulb (lamp A)

-.. I know it is definitely not 5 minus 3.3 A.
I can not work it out

I. If there is one bulb instead of the two in series ?
In other words if it was similar to this circuit
(diagram below:)



S. ..... this is not going to help much. In this case (A.) the current is not used .
There is no bulb (before the current splits up) ...
this 1.3 A it is before it is used up by this bulb (bulb X)
unlike the second case where the bulb Y comes before the ammeter

The protocols listed earlier do also indicate that current is used / is less after a resistor.

Other cases:

1. .Since there is a resistor, the current is going to part with some electrons here .. ..will sort of gain some electrons from the battery

S.11 ..some of the electrons are used, and those that go through will be used afterwards in this part

S.8 ..the current is less because some of the electric current is lost (in the lamp)
because some of the electric current has been transformed into another form of energy which is light.

I. How can electric current be changed to light? since it is not energy itself?

S. 8 .. .. it carries this energy which turns to light .. ..
it will have less energy after passing the lamp

S.23 the current will be less than 1,9 A ..(Reason?) ...the resistance of the lamp. ...the current is used by the lamp

The thesis here is <u>not</u> that students continuously use particular models to the exclusion of others, and that they consciously evaluate the current models that they hold. In fact, in the investigation some shifted from one model to the other. It is rather to say that students use certain types of incorrect models (and conceptual frame-works), which are not generally acceptable to the scientific community, in reasoning about electric circuits, and that in so doing they may be [and are very often] prevented from grasping fundamental unifying concepts like those of conservation of charge and current in a circuit. It seems that the overriding misconception that influences the models is that since electricity [=current] moves from the battery and causes the lamp to light, it is therefore 'reasonable' to expect that the current would not be there or be less after the lamp since it was going there.

(4) There is a strong association between current and energy; between electric current and electrical energy. This is evident from the multiplicity of instances the two are used synonymously. In fact, as reported earlier, students are more inclined to use the word electricity. This most likely arises from common sense usage of these words; where we find that

-- electricity (current) is used for lighting
in heating up our homes, to run machinery etc.

As a result students understand a battery as " an energy source", to be a "source of electric current". Current by its nature as perceived in life-world situations will always have energy connotations. The second consideration is that, in life situations, even the phrase 'use of energy' in the primitive meaning does not imply that there is energy afterwards even in another form; ie it does not imply the principle of energy conservation. In those situations energy is just used; certainly some benefit is got out of this but that benefit could be anything. The benefit is least thought of as energy still.

The fundamental form of energy which students understand and relate to, and which is introduced quite early in their studies is that of energy because of motion. Consequently a high value of current suggests that the charge carrier particles (electrons) there have a high energy, have a high kinetic energy. If current passes through a resistor the charged particles must lose at least part of their (kinetic) energy.

There is no clear cut separation conceptually between current and voltage ; since fundamentally a battery provides energy; that is, supplies electricity or "current"; and at other times it is referred to as a source of "voltage" or electromotive force.

(5) The last aspect on the ideas about current is linked to its visibility and its perceptible effects like shock and electric sparks and fire. It has basically superstitious origins. Often we have observed students, university students, connecting simple circuits, eg potentiometer circuits, bridges etc; in physics practicals classes. If given some decision making and allowed to connect their circuits, students often use sources which are too powerful for the potentiometer wire, and as a result too much current passes through the wire and it becomes elongated, red and even white hot and eventually breaks. The last thing they anticipate is any sparks, or short circuit resulting in red potentiometer hot wires that seem to twist, elongate and burn out or even shock. Whilst doing mechanics experiments on an air track they often get a slight electric shock on activating the spark timer. I have observed many of them not willing to continue with the practical exercise after these experiences, purely on suspicion that there would be an inexplicable short circuit, spark or even experience of electric shock. Some students tend to think that

current behaves in unpredictable ways, is lurking there waiting to pounce on them. This has been highlighted in an earlier section.

The tendency to think in this particular way, needless to say, hinders the growth and assimilation of fundamental concepts about the basic behaviour of electric circuits; as a matter of fact, of all science.

4.2.3 Electrical Energy:

The electrical circuit is the paradigm of a physical system which consists of several components like a battery, a bulb, resistor wires a switch etc. Although there may be many concepts that come into play here, like charge, current, voltage, emf , power etc; the central one is without doubt energy, in its various forms, and its conservation. The analysis of the electric circuit must happen when the circuit is a closed circuit; when the system is running at the steady state ie when there is current flowing.

Students fail to address the aspects listed above and tend to worry about the isolated physical observables, ie the battery, the wires, the lamp, the resistor and of course the invisible charge (or charges, which are only conceived as charged particles), and elusive electricity (whatever that is -energy or current-). They fail to understand the central role of energy and, in their attempt to make use of the word, they also show their basic inadequacy in conceptualising the entity.

In the analysis above it has become obvious that energy can be one of many things. Energy may be variously referred to as

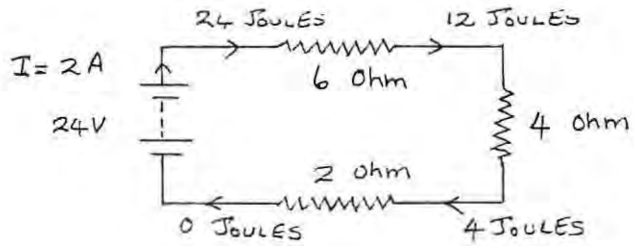
(i) Electric current

(ii) Voltage

(iii) Electromotive force (as a force)

(iv) Heat, light, form of motion etc

Traditionally in teaching at the schools' level the explanation given is that the energy comes originally from the battery and may be identified / recognised in the circuit in the potential (energy) difference of the charged particles (electrons) flowing in the circuit. The overall impression is that the flowing charged particles (=electricity) possess the energy on leaving the battery and shed it sequentially on passing through the other circuit components; resistors lamps etc . Through want of a more appropriate model this energy is viewed as being transferred from the battery to the other parts of the circuit in a rather mechanistic (atomistic) way. It actually moves there physically, carried by charged particles. I have discussed this point of view in an earlier chapter.



As the d c electrical theory makes use of the other concepts like charge, electromotive force, resistance heat and light energy etc, invariably these latter concepts, although accommodated, are used rather simplistically by the students to further explain how the energy is transferred to the various points of the circuit. That is why current has to set out from the battery in this view.

In this research I have found that there are basically four different ways in which the transfer of energy is explained:

(i) The electrons (whose flow constitutes electric current) are released and repelled by the strongly negative electrode of the battery and diffuse along the circuit from where they are many to where they are few. They are also being attracted by the positive pole of the battery. In some instances the electrons will eventually neutralise the positive electrode after which there will be no current flow.

(ii) The most popular way of thinking is that the energy from the battery is the kinetic energy of the charges moving along the circuit. This energy is passed on to the resistors including lamps in the circuit through the loss of kinetic energy of the electrons, and changes to light and heat etc. As a result the electrons would have less kinetic energy on the other side of the resistor.

(iii) The charged particles may acquire this energy from the battery as a force, and the electrons will have less force on the other side of the resistor. This is influenced, I think, by the use of the word electromotive force; the old often so called Aristotelian conception that a particle moves along because it has a force inside it, and that resistance (of the lamp) dissipates this force. Sometimes this energy is called voltage and is dissipated in any resistance in the circuit.

(iv) Another outlook is that since the particles are charged -"charged" meaning energised or filled up with energy, the electrons will lose this energy at the resistor and it will turn into light and heat. In this theory some charge will be lost at each resistor, or lamp, and there will be less charge on the other side. This leads to non-conservation of charge in the circuit. The misconception probably results from the popular use of the word

|charged| in life world situations; for example a battery is charged in order to get more electricity from it.

(v) And yet another incorrect conception, perhaps less popular, is that charged particles themselves (=electrons) will become less on the other side of the lamp. Naturally this cannot be allowed because it would lead to the loss of mass at the lamp or resistor; mass would not be conserved.

S. "light comes off from the lamp because some electrons have turned into light"

Most of the incorrect current models result from attempts to grapple with the electric circuit as an energy system. I have shown earlier that some students confuse electric current with energy.

An underlying inadequacy in their reasoning is that non-observables do not exist. In all their conceptualising students are in a deep quagmire, trying to reduce all energy to a form which they can experience or observe. They fail to conceptualise the much broader nature of energy. Most forms of electrical energy are translated / reduced conceptually to kinetic energy. When discussing resistors and lamps etc, they invoke usefulness from the human point of view, and of course visible effects. Hence a lamp will use more energy (current) than an ordinary resistor.

Subconsciously perhaps, students worry about the mechanism of energy transfer (from battery as chemical) to the lamp appearing as heat, light, and create their own models ie. that current carries the energy / is the energy, changing to light, heat later at the lamp, resistance etc. They worry about what the actual form of energy is, if it has certain specific forms or whether its form is the effect it has where ever this may be perceived

/ observed. They try to idealise how as an entity it is carried from the battery to the lamp. My experience has been that at this stage they have not assimilated the concepts relating to the emission of light (or other form of energy) when an atom/ion tranforms from one (higher) energy state to another (lower) energy state. To many of them light itself is primarily a sensation and not a form of energy necessarily . It is important that they be helped to thinking in acceptable ways about science. Their thinking about phenomena is perhaps still at the informal and casual level, and is not an adequately sophisticated form of abstract thinking. At this state, when relating to simple d c simple circuits, the issue of the conservation of energy (and not its use) has to be addressed. The use of energy is a life world common sense aspect.

During the interviews, we got the definite impression that many try very hard to actually describe the mechanism of electron conduction, feeling a subconscious need for covering this ground, by indicating how one electron pushes another and the other pushes a second one further removed etc. Inside the resistors the electrons are 'squeezed' and 'squashed' and rubbed against each other, so that the expected heat and later light may be actualised. Should scientists not take them out of this pain by creating better models and introducing more adequate thinking formats earlier? Should we not encourage them to make the conceptual leaps, convincing them that the physics of one's own concrete experience is not necessarily going to be adequate in explaining everything; that there are general or established ways, (or structures / frameworks) in which scientists think? The mechanism of energy transfer is a case in point here, and so are the different forms of energy.

The concept of electrical potential energy is not developed, it is merely mentioned but not adequately covered in school texts and by teachers. Other studies cited elsewhere in this work confirm this [Shipstone, Riley, Rhoneck]. Traditionally teachers and textbooks cover this ground sparsely and quickly move on to calculations involving the use of

V=IR; and these calculations particularly emphasise the overall importance of electric current, its 'uses' etc; and not of energy,

Potential energy as a rule is associated, by students, with gravitational potential energy from gravity theory. This gravitational potential energy is normally transformed/exchanged to kinetic energy when a body falls. In the electrical case students expect as well as assume that change/drop of potential energy (and potential difference) is in all circumstances equal to kinetic energy loss or gain. We know that in the electrical potential energy model the theory is more complicated than this. There are obstructions (in the fixed lattice positions) as the particles fall through the declared potential differences, and the energy exchanges are not as simple as in the gravitational potential model. This will be discussed again in the next chapter.

My standpoint was that if any one has an understanding of potential difference it may be expected that they are familiar with the concept of electrical potential (energy), the difference of which is the issue. My scrutiny of students' understanding of potential (energy) indicates clearly that they are not able to express themselves on it at all, to any satisfaction.

Here are some protocols:

Electrical potential... is the ability of a circuit to produce a current across it.

- is the strength or energy the battery gives to the circuit
- is the amount of energy a cell can give
  and it is stored in the cell
- is the power in the cell
- is the indication of the cell's capacity to do work,
  either by production of heat in a circuit

The explanations here, one can see, are derived from literal meanings and are not from a scientific model at all. This also indicates that the students have not been put through the paces of the whole theory leading to potential difference being potential energy difference per unit charge. They merely understand it as 'some volts' or voltage. This invariably leads to confusion between potential difference and emf; between the energy giving and energy taking aspects of a d c electric circuit.

Some explanations of emf and its relationship with potential difference follow:

1. emf .... is the "force" required to drive a charge through a circuit. ..without a p.d. there would be no emf to drive the charges.

2. emf .... is the force that is used to flow the electrons. The difference between it and the pd is that one is a force whilst the other is a difference

3. emf ....is the force applied to the circuit. It is the same as p.d as both of them are the amount of energy needed for the flow of current.

4. ...is the same as p.d .. it is the voltage that is flowing per unit length ....and is directly proportional to the electrical resistance.
(Highlights the use of formula V=IR in defining p.d)

The concept of electrical potential energy needs to be developed adequately.

Further:

Potential (energy) difference => (loss/gain) of energy per unit charge
=> Gain of Kinetic Energy per unit charge

suggests to students' minds that each charge (carrier) has less kinetic energy down the line, where the potential is less. The reasoning here is comparable to that of:

loss of (gravitational) potential energy = gain of kinetic energy for falling objects (studied earlier in gravity situations).

A more appropriate conception of electrical potential energy of a charge is that it is a measure of the extent of the energy it will cause (by virtue of its position/state) to be exchanged out (out of the electric system) in some form either as heat, light etc. The particular charge (charge carrier) may not be thought of as possessing all that energy at any point in time. So, unlike the simple gravity case it may not be assumed that the charge carrier possesses all the potential energy (eg. mgy, whatever this means), at the onset of its journey through the circuit and that it merely releases it as kinetic energy in parts as it goes through the resistors on the circuit.

It seems that the characterisation of energy in terms of how we sense it (as light, heat, as motion etc;) intervenes to make learning more difficult. In the students' minds the sensation (light, heat) is unfairly highlighted in the total concept being portrayed to the exclusion of the fact that we are talking about energy. This could be because the sensation is more real to them as a concrete experience. The conservation of energy principle is not reinforced as such when the light (=energy?) comes off from the lamp. In the electrical energy context the students expect the energy to be in terms of an observable form and characterise the potential energy in p d not suprisingly in terms of the senses as kinetic. It seems that it would be wiser to talk in terms of "energy which we perceive as light" which comes off at the lamp instead of "light comes at the lamp".

Words, and their meanings, play a significant role in the formation of concepts by students. There was abundant evidence that students think of electromotive force as a "force". There are at least two complicating factors involved here:

(a) The first one is that of language. The secular meanings of the words "force" and of "energy" in the African languages of the sub-continent of Southern Africa are the same, 'amandla'. Hence there is no apparent disagreement between the words 'force' and 'energy'. One has to think carefully here and may even legitimately suspect that, possibly in the very minds of those who initiated the basic theory there could actually have been some confusion at the beginning, about whether emf was a force. Hence the pressing need to restructure scientific knowledge into a more digestible form for the students we teach.

(b) Students tend to readily adopt the so-called medieval Impetus Theory (related to the Aristotelian theory); that a particle (=electron) may have a force, (actually contained within itself) imparted to it earlier, on being subjected to an external force. The particle would then, according to this theory, be able to remain in motion until all the force imparted (earlier) to it is dissipated by -- resistance -- or resistive forces; ie the electrons will be able to continue around the circuit until they have lost all the electromotive 'force' given to them by the battery.

Evidence:

Student: Tyana:

S. The electrons have a force. ...that's why they move in the circuit .. .. a force given to them by the battery.

I. How does the battery give a force?

S. I am not sure .. .. Eh! .. maybe they are repelled by the negative of the battery. The battery has the electromotive force, which it gives to the electrons on leaving..

I. Meaning that there are no electrons in the resistor?

S. No I dont think so .. ..the electrons come from the battery where they get the (em) force.
When they pass the resistor or bulb they lose some force, because the resistance opposes them. ..and now they will have less force.

They will have no force when they get to the battery.
This force is changed into light in the lamp.

The lamp X will be brighter (than Y) because electrons
get there with a large force since it is near the battery.

Other examples: (extracts from other students' interviews)

1 emf is the voltage that is flowing in the circuit

2. emf is used up during the conduction of electric current,
It gets less and less. It cannot be conserved in the circuit

3. emf renders some electric force to the electrons to
move about in a circuit

4. My thinking is a bit clouded in this respect ....in that
I am inclined to think that it (emf) is a force which is
applied to the electrons to cause them to move in a circuit..
-- but, since the mass of the electron is so small that force
is taken to be negligible

It is obvious in this situation that the language is not only inadequate but that it is misleading as well. The language is neither correct nor sufficient. This would naturally disorient the thought structures in the mind of the student.

4.2.4 Potential difference: (OR 'Voltage'):

(i) The first thing to point out here is that in this investigation I found that students prefer to talk in terms of 'voltage' and will only refer to potential difference if you mention it. I have established that they speak of voltage even when they refer to the electromotive force. Also, there is the general misconception that electric current is energy and is supplied by the battery.

In the research I have found that the spontaneous explanations of electric circuit phenomena given by students were invariably always in terms of electricity, electric current, 'voltage' and power; hardly ever in terms of electrical energy, potential (energy) difference or even electromotive force. These findings compare with those of Cohen et al [1983], and Shipstone [1984], and illustrate quite clearly that the concepts of emf, potential (energy) difference are very poorly conceptualised by students although they are more fundamental to the theory.

Electrical potential energy and especially potential energy difference (=p.d) are extensively used in the development of the theory but are not ever adequately developed in actual presentation procedures. Instead even the word **'energy'** is habitually left out in potential (energy) difference. The traditional approach of most textbooks and teachers is to introduce simple circuit theory by way of use of the formula V=IR and problems which require almost exclusively the calculations of I, R and V etc, without an intelligent understanding of the electric circuit as an energy system. The equation V=IR as it stands, and is used, does not really tell us much about how the system works and is not the best way of introducing the electric circuit as an energy system.

It seems to me that the traditional approach to the teaching of electricity at high school and even at university is highly formal and abstract and no student who has not had experience (including especially practical) with simple electric circuits may be expected to understand their operations in terms of abstractions like charge, energy per unit charge, potential difference etc.

My analysis is that in the minds of students 'voltage' has taken over from potential (energy) difference or energy difference per unit charge. Voltage has tended to adopt even a special meaning of its own. One finds that it is used for both potential energy and potential energy difference. The thinking is along the following lines: Potential is expressed in volts and potential difference is expressed in volts (as a voltage) or volts difference. This seems to suggest that where there is a p.d there is a volts (voltage) difference; that there are more volts at the high potential side than on the other side. As a result the conclusion is that volts disappear in the resistor; volts are consumed by a resistor. Naturally this leads to the further incorrect conception that voltage flows in the circuit from points where there is more to where there is less, and is used by circuit components like lamps.

Volts or voltage is then understood to flow from the battery.

Secondly some students accept that the charged particles flowing in the circuit acquire some volts from the battery (since it is the source of emf - also measured in volts); move around the circuit because they have the volts and will lose some volts when they pass through circuit components eg. lamp. How many volts are lost may be calculated using the Ohm's law equation. In this last sense volts are interpreted to be energy which the charged particles receive from the battery before setting of through the circuit.

1. ...the electric resistance is trying to control the amount of voltage flowing in the circuit by reducing it.

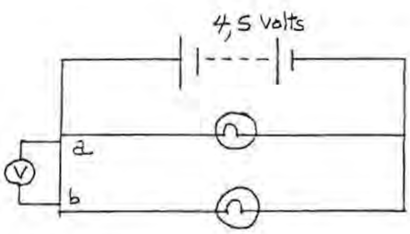
2. ..it (voltage) will be 4,5/2 volts ... the lamps are connected in parallel so they are rather sharing the volts that come out of the battery (see figure below)

Student: Sebenzile

S. To my thinking, Mfundisi, [Sir] some volts are going to be lost in the lamp. So the second lamp [two lamps in series] will have less volts ....
In order to light it [the lamp] must use volts

Student: Motumi:

two lamps in parallel



S. .. the voltage across the lamp will be 2,25 volts.. because, now these bulbs are of the same kind, Now they are connected in parallel.
You find that as the voltage comes at this point, it will be divided into two equal parts.

Each (lamp) will be experiencing half of the total potential or voltage.

If the resistance of the lower lamp is doubled, then the voltage across the lower lamp will be double that of the upper lamp.

To my mind 'voltage' is one of the most misused words, by both school teachers and subsequently their students, in electric current theory and it would be better if it were not used at all. In fact the whole of this theory is replete with "words for concepts" that ought not be used at all, because they tend to confuse pupils, many because of the common sense meanings attached to them. I will discuss this point later. For 'voltage' whenever possible the words potential difference (measured using a voltmeter), electromotive force could be used.

Because "Voltage" expresses directly and indirectly both potential difference and electromotive force, confusion reigns. The expression makes it absolutely impossible to distinguish between the energy exchange aspects / roles of batteries (cells) and other circuit components. It is obvious from the manner in which the word has been used that "voltage" has taken on the status of a separate physical concept [something flowing out of the battery] and yet it is merely the result of the measurement of 'p.d' and/or 'emf'. Often if one indicates that a voltmeter is used to measure emf students take this to mean that one wants to find out how many volts are remaining stored inside the battery still to come out. The battery would run 'flat' when there are not any more volts that can come out.

Quotes from some interview protocols:

S. ....p.d is the amount of voltage passing in a circuit

S. ....voltage is the ability of a battery to produce charge across

S. ....without voltage there would be no emf to drive charges through the circuit.

S. potential difference is the power in the cell ....it makes the current flow.

It seems that the framework of *some volts disappearing at the lamp* does fit conceptually in the minds of students with the notion that "volts" are supplied by the battery to the lamp and become less on the other side of the lamp. Voltage is at least one entity that is different on the two extremes of a lamp.

(ii) The discussions earlier and the protocols in the last paragraph indicate that there is not clear cut separation in students' minds between electric current and so called 'voltage'. There is much evidence accumulated, including by others Rhoneck [1983; Shipstone 1984; Cohen et al 1983] that students experience great difficulties in discriminating conceptually between current and 'voltage'. Current and voltage are both subconsciously treated as 'energy supplied' from the battery. My interpretation is that these problems are caused by the fundamental lack of distinction in life-world situations between electricity, the energy, and electricity, the electric current; and an inadequately elaborated conceptual model for the 'supply' of the energy from the battery to the lamp etc; in the circuit. Hence the conclusion that volts are supplied from the battery. More fundamentally, perhaps, this is caused by the failure to emphasise the energy conservation principle and to present the electric circuit system as an energy system.

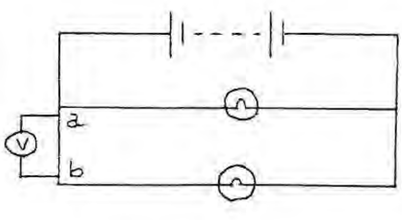
The students think of current as the primary concept and potential difference as consequence of current flow, and not its cause. Voltage is linked to current by way of

V=IR. I have found that more than 50% of the students think of and define potential difference solely in terms of the Ohm's law equation V=IR.

Most students need to be helped with the phenomenological reasoning about energy when elementary resistive direct current circuit theory is introduced at the beginning. Conventional textbook presentations and teachers do not do this. Instead the problems and tests, used often after a cursory effort, hastily channel students into exercises with the use of formula for series and parallel combinations of resistors or into obtaining circuit equations by application of Kirchhoff's rules. In the majority of these it is mostly the current that has to be calculated, sometimes the potential (energy) difference, using Ohm's law. It is this approach which tends to make the student consider current to be the prime concept and 'voltage' secondary. These could be treated as sub conceptions which are necessary to explain the main ideas of energy exchange in a d c circuit.

There is another very important factor that influences this inappropriate conception, which I have mentioned earlier. The general misconception inherited from life-world situations that electric current is electricity (as 'used' for lighting, heating etc) also encourages the idea that current is the prime / or leading concept.

<u>**Student: Nase :**</u>



S. I dont know the current here so cannot calculate the voltage here

I think that the V will read half of the emf ...which is 2,25 v here {across one of the lamps}

I. How did you work this out?

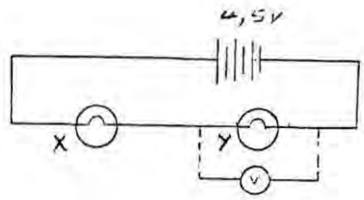
S. These bulbs are similar, now, the current at this point, the fraction of this current will flow to this direction, ...now, so the p.d will be half of the total p.d

I. Why should the voltage be half?

S. Because half of the current goes this way and the voltage can be calculated from the current

Another protocol:

Student: Pepa:



I. What is the potential difference across this lamp (X)? [lamps X and Y are identical]

S. ...Eh!!.. I am not sure of the current here of X Unless I know the current and the value of the resistance of these lamps here. Then I will know the voltage {via V=IR}

Later

the reading will be the 4,5 v for the first lamp ... and even for the second lamp, because same current goes to the second lamp

I. What is potential difference really?

S. It (the potential difference) is the voltage between any two points of a conductor in which there is 1 amp when r = 1 ohm

I have found that more than 50% of the students think of, and define potential difference in terms of Ohm's law formula V=IR. The last two protocols substantiate this viewpoint.

These interviews give further insights and highlight the confusion in students' minds when it comes to thinking about emf, potential difference, voltage etc, and the relationships between these. The above examples illustrate very well how the current as the primary concept can lead to wrong conclusions about potential difference. However, I must point out here that one cannot be certain that voltage 'flows' in the two directions because voltage is energy (will discuss this in the next paragraph) or because current (as energy) is primary.

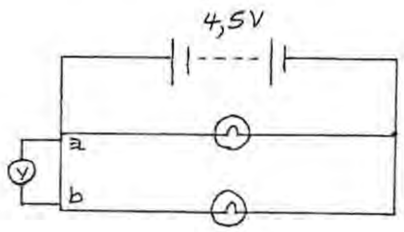
Students very often use formulae (= thumb rules) to escape thinking more rigorously or because they see the formula as the real science, as the tricks to be used as part of science. Certainly this approach brings relief because, after this, there is no need to think further about it.

(iii) In a significant proportion of the cases (60%), students think of voltage as just plain energy, as something that flows in very much the same way as water in a pipe or as the current, that is 'consumed' by the other components of the circuit. Voltage is always there (possible to measure) in any one point of the circuit, since it must flow through that point.

I interpret this to be another way students are trying to explain the mode of energy transport from the battery to the lamp. In is my view that the conceptual frameworks used traditionally to present d c theory do not cater satisfactorily for the transfer of energy. It is difficult for students to understand what is actually taking place in tranfers of energy when less observable forms of it, such as potential energy are involved.

Examples:

1. ..electrical resistance serves to control the amount of voltage flowing in a circuit by reducing it.
2. ..p.d is the amount of voltage passing through in a circuit
3. ..emf is the difference between the voltage that is flowing in the circuit and the internal p.d of the cell



I. What will be the reading on the voltmeter in this case? (between the points a and b)

S. It (the voltage) will be 4,5 volts .. .. it will be there alright

I. Does it not worry you that there is no electrical component in between?

S. No, that does not worry me .. .. there is current passing at this point, ... so there must be voltage

(iv) There are two aspects to the definition of potential difference as energy per unit charge, that bother students.

(a) The first one is that of potential difference (voltage) being expressed as a ratio.

As mentioned earlier, students are forever confused by rates, ratios, and proportion. Here again we also made out that a large voltage (meaning large electrical potential really) implies a large number of electrons (or charge carrying particles) at a particular point in space and time.

The basic reasoning for the inappropriate conception here is that if there is a comparatively large number of electrons on the one side of the resistor, some of these apparently change into light or heat (energy) on passing through the resistor, resulting in a fewer number of electrons coming out on the other side. The larger number of electrons on the one side, compared to the other side, would then account for potential difference across the resistor. This is measured in volts using a voltmeter and would be considered to be a 'voltage' difference. It is in fact true that an electron concentration gradient across any two points would establish a potential difference between the points, more charge at a point, larger potential. A most fundamental and worrying aspect of this reasoning is that it leads to the nonconservation of charge (and of matter as well, in fact) as it assumes that charge (or charged particles = electrons) is lost on passing through the resistor.

(b) The other aspect is related to the inappropriate conception that charged particles have their average kinetic energy reduced on passing through an extended resistor; that the kinetic energy lost by these is a measure of the amount of electric current 'used' by the resistor.

The vast majority of students, 80%, invariably think of energy per unit charge in terms of kinetic energy per unit charge. Hence the evidence that there is a higher potential on one side of a resistor because the electrons have a higher kinetic energy there:

Student: Leepi

Figure on page 170

S. The speed is the same here. So there is no potential difference between the points a and b.

If there was a torch bulb here at this point, the electrons
would have been slowed down by the resistance of the bulb ..
and there would be a p d between the points a an b

The electrons (charged particles) are slowed down in the resistor to emerge on the other side with less kinetic energy and hence a lower potential.

Typically students are in fact all the time thinking in terms of charged *particles* (perceptible in mechanical terms) and not in terms of charge. There is an oversimplification of the mechanism of current electricity 'conduction', a simplification to a more 'concrete level' and this tends to overshadow the fact that electric current is actually defined in terms of charge per unit time and not in terms of electrons passing per unit time. Typically school texts explain electric current fundamentally as the flow of electrons or charge, although they do make mention that it is the rate of passage of charge.

4.2.5 Electrical Resistance :

(i) Conceptions of electrical resistance for most students are linked to the energy exchange relationships in simple circuit theory. They are very much associated with the idea of heat, and light being given off by a lamp. As a result resistances are seen as energy converters or users. Students often invoke usefulness at the point where the resistor is situated in the circuit; for example, reducing the current as it passes that point.

Student: Thedi

S ....if it (the resistor) does not "use" any current what is
its purpose in the circuit?

(ii) Resistance is understood to oppose and use electric current, and to make it less than it was before. One has to mention here the possibility of the interference of the medieval impetus misconception inherited from mechanics in the intepretation of the role of resistance in electrical circuits: A very popular misconception which comes out in mechanics (and is inherited from life world situations) is that a body carries on in motion because it contains a "force" (=emf?) within itself. The force wears down due to its consumption by the motion or is dissipated by resistive media: Thus Resistance opposes an applied force or consumes the impetus of the moving object. In the same sense electrical resistance opposes / hinders / dissipates the electromotive force (as for actual force) of the flowing charges, sometimes also the speed of the electric current; thus reducing it. These points have been highlighted well in the student protocols above and have been discussed at length in the earlier parts.

(iii) In the most common frameworks students in this research see a resistance as something that dissipates current in a circuit and/or pushes against an already flowing current. For example, it may not be expected that in some situations [eg two resistors in parallel arrangement] an additional resistor may actually help "draw" more current from the battery, than when there is only one of them, in the circuit. There is no doubt that this inappropriate outlook is reinforced by the misconception that the current emanates from the battery and has a preset value, and that its amount as originally supplied is not altered by the 'size' of the circuit components (= the resistors) nor their arrangement. With two or three resistors arranged in series, the perception is that the particular current incident only changes when it gets to a particular resistor or point; this was indicated when the so called sequential model of current was discussed.

(iv) A related misconception is that the role of the resistance is to reduce the average kinetic energy of the electrons (or charged particles) as they pass through the resistor, in the sense that the kinetic energy of the electrons (or charged particles) will become less on the other side of the resistor. This idea reinforces the misconception of loss of current (measured in terms of K E of the electrons) as it passes through the resistor. This would result in a potential difference across the resistor (V=IR); and hence I also found the misconception that there is a potential difference between any two points because there is a kinetic energy (of electrons) difference between the two points.

(v) An understanding of the role of resistance is central to the theory of simple circuits. Most students do not understand that resistance is inherent to circuits; that every component in a circuit has an intrinsic resistance including leads, lamps etc. They think the lamp is there to simply take off light energy from the system. They prefer to think that a resistor is always introduced for certain effects like applying brakes to the current (reducing the speed of the current), and to cause heat. The thought that electric circuit components other than wire resistors, are characterised by the value of their resistances for the purpose of calculating current, power factors and so on, hardly ever crosses their minds.

It has not been possible to determine categorically which one specific misconception brings forth this incorrect reasoning. The dominating one could be that current is "used" in a resistance (and converted to energy, to light, to heat). The other could be that the electromotive 'force' which the electrons possess (imparted to them earlier by the battery) is dissipated by the resistance, as the resistance opposes the movement of current.

(vi) The interviews showed that about 70% of the students have no clear understanding of a short circuit. Zero resistances ironically implies no connection and therefore no current (especially for parallel resistor arrangements) in that limb, whereas it should imply

imply maximum current in that branch. This point has been presented and exhaustively discussed in an earlier chapter.

S. (Tyana) .....Short circuit means that less current is wasted because it does not go through the lamp, it goes by the short cut through the wire instead

4.2.6 Implications for problem solving :

The misconceptions and tendencies in interpretation, which we have discussed above, manifest themselves very clearly when students are dealing with problem solving related to direct current theory. This is especially true in situations where the students would normally be expected to make some intelligent use of Kirchhoff's rules in more complicated circuits. When confronted with problems their techniques and tactics are typically simplistic, short and easy to follow.

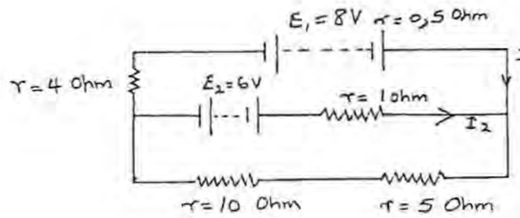
The most characteristic habit is that of making blind use of some related formula, especially the Ohm's law equation V = I R. Invariably the statements of Kirchhoff's rules

$$\sum E = \sum IR \quad \text{and} \quad \sum I = 0$$

at a junction, do not make much sense and are seldom applied correctly.

Examples:

(i) Consider the circuit represented by the diagram below.



If an emf source with an internal resistance indicated is used, the students often make use of the value of the internal resistance to determine, via Ohm's law V = IR, the 'amount' of electric current which is "supplied" by the battery.

Typically in the above case the calculations would be as follows

$$I1 = \frac{8}{0,5} = 16 \text{ Amperes}$$

would be the electric current "supplied" by the battery (source).

The current through the 1 ohm resistor would be

$$I2 = \frac{6}{0,1} = 6 \text{ Amperes}$$

because the 6 volts source is nearest to the r= 1 ohm resistor.

The students were found to use solution strategies which typically are mechanically guided by local features of the problem. There was no attempt to do a global analysis of the propositions and to consider the givens in the particular problem first. Instead, the tendency of student is to retrieve isolated principles, particularly formulas and use the quantitative information given to guide the solution procedure. The major tool seemed to be the Ohm's law equation V = IR, and it would be applied indiscriminately to any local situation. Almost by some instinct they expect to manipulate this information using the primitive mathematical operations of addition and multiplication; to produce the answer required. It seems the main object of the exercise is to produce an answer.

(ii) In the circuit above only the one source, either E1 or E2, could be responsible for the current in two (5 ohm and 10 ohm) resistors in series.

A typical approach would be that since E1 (= 8 volts) it would overcome the force of the E2 = 6 volts and the current I3 'in' the 10 ohm resistor would be caused by the 8 volts:

$$I3 = \frac{8}{10} = 0,8 \text{ Amperes}$$

Note the use of 'in' the resistor as if the electric current resides inside the resistor. This is a popular posture among students. Teachers use this kind of language as well. To my students this would suggest that the current is presently at the resistor being used and that anywhere adjacent to the resistor the current would be different. It would be preferable to use current through the resistor.

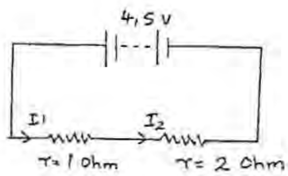
(iii) Characteristically, if there are two resistors in series as indicated in the lower loop, the electric current in the 5 ohm resistor would be

$$I4 = \frac{8}{5} = 1,6 \text{ Amperes}$$

The current through the 5 ohm (= 1,6 Amp) is thus different from and larger than that through the 10 ohm resistor (0.8 Amp). The interview protocols earlier have already shown that this is the procedure used by students even with much simpler circuits; namely, the current is not the same 'in' two (or more) resistors connected in series.

For example:

In the circuit represented by the diagram below, the calculation of the current might be as listed:



$$I1 = \frac{4,5}{1} = 4,5 \text{ A} \qquad I2 = \frac{4,5}{2} = 2,25 \text{ A}$$

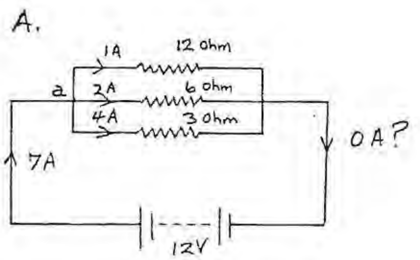
(iv) Typically no attempt is made to conserve the current (or even charge) at any junction in the circuit

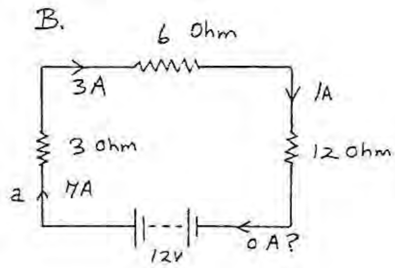
Hence in the Figure above Page 175

I1 ≠ I2 + I3 that is 16A ≠ 6A + 1,6A

In most other situations the source which is nearest to the resistor or other 'obstacle like lamp' is the one that supplies the current (via V = I R) to that particular resistor. The current is calculated by way of V = IR.

(v) Consider the following circuit





If the source E1 is the only one in the circuit (Figure A), then the electric current is distributed in such a way that each resistor receives its share of the current.

This is found in the following way:

$$I3 = \frac{12}{3} = 4A \quad I6 = \frac{12}{6} = 2A \quad I12 = \frac{12}{12} = 1A$$

Therefore the current supplied by the source is (4 + 2 + 1) = 7 A

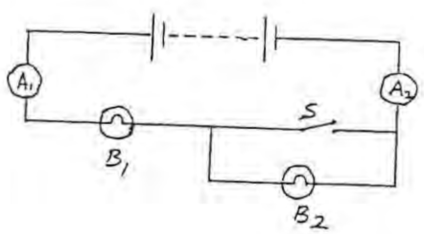
The source (the 12 volts) is assumed incorrectly to supply the same amount of electric current if the resistors are arranged in series [Figure B) as when they are arranged in parallel (Figure A). The corresponding resistors " share / use" the same amount of current as in Figure A. It is 'reasonable' to expect this in any other series and parallel combination arrangement.

This very strong misconception that current is shared makes most students assume that the current

(i) arrives with the same speed [= 7 Amp] at points a in both circuits.
(ii) is shared in the manner shown in the diagrams of both circuits, - such that zero current returns to the battery.

The example which follows now indicates that the problem is much larger and has wider implications.

It was taken from a national S.T.D Physical Science Examination [1986] for teachers of physical science to be.
Question:



(a) .....
(b) .....

The switch S is now opened

(c) Compare the brightness of the bulbs B1 and B 2,

before and after the switch was closed.

Answer: [as given in the marking memorandum]

B1 and B 2 will have the same brightness but will

be less than the original brightness of B1. [*fair enough]

(d) What happens to the readings of the ammeters A1 and A 2?

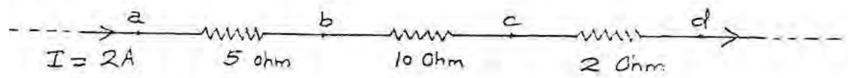
Answer: [also given]

There is no change [from previous, when the switch S was open]

It is remarkable that the examiner (who supplied the answers) although prepared to concede that the brightness of the lamps must be lower, still maintains that the electric current readings in A1 and A2 will not change. This I presume is because he is influenced by the incorrect conception that the electric current is "supplied" by the battery and has a constant value in both situations.

The problem situations cited above and many others I have met, indicate that students do not conserve energy in electrical circuits and that they are unable to apply Kirchhoff's rule.

In order to test for an understanding of electrical energy and/or potential difference situations, and partly to obviate the difficulties experienced by students as listed above, I have often set questions where only a circuit current loop is indicated (see the diagram below).



Students are often stumped by this kind of problem.

Their arguments are typically along the following lines:

[For the first resistor: V = I R = 2x5 = 10 volts and

for the second V = 2x10 = 20 volts

This would make the voltage of the 10 ohm (=20 volts) higher than that of the 5 ohm resistor.]

Student: Nyiki

S. Sir, this answer is not possible. The current cannot move in the way shown in this drawing

I. Why/How? can you explain

S. It is not possible because, for the current to move in this direction [a towards d] .. .. this [5 ohm] resistor has a lower voltage than the other [10 ohm] resistor .. .. and current always moves from where the voltage is high to where it is low, but in this case this is not so.

The current should move in the opposite direction, from d to a.

A most popular strategy in problem solving is that of committing to memory previous solutions and hoping for the best; that is, for exact or similar problems to be asked in the examination. My experience is that students are very bad problem solvers, and that only about 20% approach these tasks in any methodical fashion.

On the whole the difficulties of students in problem-solving have been those indicating lack of depth of understanding of the theory, and their procedures in problem solving have been found to be characteristically brief. They have been easy to diagnose as the students always attempt to fall back onto using a formula in a simple and direct way.

4.3. Conclusions:

On close examination of the misconceptions established so far, one finds certain fundamental underlying incorrect ideas which may be summarised as follows:

A: <u>Current</u>

The conceptual models of the students do not correspond to the 'standard model'. The conceptualisation of electric current as a rate of flow of charge has not taken root. Instead, students use models of current which may be built loosely on ideas of energy and / or moving charged particles. These models have some or all of the following attributes:-

1. Current is something that flows from one physical point to another in a circuit.
2. Current is *supplied* by battery to the other circuit elements, and sets out from the battery. There is current in the unconnected battery since current is identified with charges

3. Current is consumed by a resistor, weakened as it passes through. The current loses its speed [as charged particles], may lose charge and sometimes electrons as it passes through a resistor.
4. Current [as energy] is *shared* by the resistors, even if they are in series; sometimes the resistor nearest to the battery grabs a larger share of the current because current arrives there with a greater speed.
5. Current is supplied at a constant [speed] value from the battery and is influenced by the other parts of the circuit only when it arrives at those parts.

B. Electromotive force, potential difference and Voltage:

In the students' understanding of 'circuit theory', the current concept is viewed as more fundamental than ideas related to potential difference. Potential (energy) difference is not fully understood and *voltage* is the dominant idea.

1. Volts are sometimes equivalent to current and energy and they flow in a circuit.
2. Voltage difference, meaning potential difference, implies that there is a difference in volts (as measured) between the two sides of a resistor, and hence the flowing volts have become less, dissipated by the resistor.
3. Potential difference or voltage results because the flowing-through charges lose speed, or they become less charged (with energy?), or that the current has less charges.
4. The electromotive force is a *force*, which the electrons acquire from the battery, and which is dissipated by their motion through the resistors in the circuit.
5. The lamp nearest the battery gets the largest number of volts because it is connected to the high (volts) potential side, and will therefore shine brightest.

C. Problem solving:

Basically students try to use V=IR in a way which takes a narrowly local view of the meaning or relevance of the given data.

4.4 Implications for Instruction:

The analysis above has established that students do have definite inappropriate conceptions, and that most of these are similar to those of other students elsewhere in the world, as published in related alternative conceptions research [Duit and Jung 1984], etc;

for example the models of current are comparable to those identified by Shipstone, Riley et al [1981], and others mentioned earlier in this research.

Experts now accept that certain forms of exposure to educational situations and learning experiences, and the lack of relevant experience, do lead to the formation of inappropriate conceptions. What has not been satisfactorily researched and documented at this stage appears to be the difficulties involved, and the techniques which are successful in getting students to change their 'incorrect' conceptions. In some cases incorrect conceptions have shown themselves to be resistant to displacement. The biggest obstacle confronting subjects appears not to be the acquisition of new strategies but rather the ability to give up existing ones. Maloney [1984], and many other experts [Jung and Duit 1984], suggest that in instruction we must not only present the 'correct' options, but should also deal with the alternate inappropriate conceptions. Students bring these to the learning situation and ideally we should know the inappropriate conceptions so that we could make learning more meaningful to students.

Furthermore, we do believe that the data gathered here, do not only give us information just about the effects of the socio-cultural background of the student as it does, but also provides us with useful information about the outcomes of certain standard practices in education in general. It does appear that a large proportion of the inappropriate conceptions are generated by the educational environment of the child in the school context; eg the teachers, textbooks etc. As a result of this the study of alternative conceptions should enable us to make some kind of statement regarding the effectiveness of certain experiences provided in the learning environment of the child. The inappropriate conceptions established should definitely have a significant bearing on the educational experiences we as instructors will provide for the learner.

Consequently we should be able to apply the results we have found in the further investigation of the correctness of current practices in physics education particularly at the secondary and tertiary level. It does appear, for example, that there is also a need to develop the forms of reasoning skills in students that are normally used by physicists. There is a need to be innovative in our presentation of the subject matter and not to rely entirely on traditional methods. We may have to adopt and design into introductory physics courses new appropriate instructional strategies to develop and enhance students abstract reasoning [Arons 1979; Cantu and Dudley 1978; Renner and Lawson 1973]. This may require for instance, the discussion of the concept initially at a concrete level Prosser [1983], the use of demonstrations, worked out examples and experiments.

In the chapter to come I will attempt to tackle some of the issues suggested above bearing in mind the particular students who come into my first year physics classes and the incorrect conceptions which I have diagnosed in them. I will make certain proposals on how the material could be presented, and in so doing may criticise some standard practices as I see them. The manner of my suggestions depend largely on the experience I have gathered over the years and have been reasonably successful with the type student who has come to my classes. I will also propose stategies which might be used to accommodate the inappropriate conceptions which I have established in my context. Again, I cannot however claim that these proposals would be successful under different circumstances although I do believe that they would be helpful.

CHAPTER FIVE:

ADDRESSING THE PROBLEM:

5.1.0 Introduction:

In the last chapter I have established that the knowledge state and perspectives of students of physics on entering university courses have a wide spectrum of determinants. Amongst these we may mention personal experience, media images, social comment and common place actions. The store of beliefs and intuitions about physical phenomena referred to above, and derived from extensive personal experience, acts as a common sense theory and is used by the student to interpret his immediate experiences including what he hears in the physics class. Whilst this store of life world knowledge, with any associated folklore and emotional overtones, may not necessarily be science, it does generate tacit scientific 'knowledge' in students. Conventional instruction fails almost completely to address these matters or to take them into account as it should. This is definitely apparent when one looks at conventional physical science textbooks, practicals programmes etc; where a theory exposition is generally followed by typical analysis (underline) or a problem whose only job is to supposedly reinforce the theory outlined.

Formal instruction should take cognisance of the fact that life experiences present themselves much earlier (and strongly), and even at school going age, more frequently than controlled specifically modelled "scientific " situations. A student would more readily accept that a body needs to be pushed (all the time) to continue in motion, than that only an initial push was sufficient for the body to continue moving along a straight line. He would not easily accept that after jogging for one kilometre no energy has been used but that the energy has been transformed from one form to another. In one of the preliminary tests given in this study 80% and over of the sample tested (N=400) felt that where two charges, q1 and q2, are present near each other, q1 will exert a greater force on q2 if it (q1) has a larger charge on it . This work and that of many others [Halloun and Hestenes 1985], has shown that students naturally characterise the reciprocal interactive force between the two bodies by some sort of dominance principle

(i) the greater the charge the greater the force
and also (sometimes)
(ii) the object which causes the motion of the other exerts the greater force because it overcomes the other body's opposition.

More recently, experts and teachers of natural science have come to realise the importance of looking closely at the science and techniques of teaching. Through research and analysis of results they have made possible the opening of windows to learners' science and theories of learning, [Fensham 1983; Gunstone 1987]. There has been a significant and welcome shift away from studies that attempt to measure success or failure in curricula purely in terms of enabling students to recall single elements of scientific knowledge. Educators have come to realise that teaching science as a set of rules, a catalogue of facts, according to which nature behaves, a set of rigid solutions to physical problems, is not the complete story. Some recognise now that although the traditional approach by teachers of asking the 'right' questions verbally and in examinations may give teachers the impression that successful learning has been achieved, unfortunately for students it is just "algorithmic" or talking about rules by the teachers and learners.

From a conference that I attended recently it became evident that even some university lecturers teach physics and chemistry as a fixed body of knowledge [Symposium on "The Undergraduate Curriculum for Teachers of Mathematics and Physical Science" Stellenbosch 1986]. Arising out of this conference a set of guidelines was adopted in an attempt to correct this phenomenon. There is greater sensitivity to the notion that the learning of the structure of the subject matter rather than simply the mastery of facts and techniques occupies the centre of the stage in the problem of the transfer. In this way the different concepts may be related to each other more meaningfully. Also, it has become imperative more than ever before that reflection on the ways in which knowledge is obtained, an epistemological activity, should be incorporated into science teaching [Helm 1985].

The study of students' intuitive beliefs, alternative frameworks, common sense beliefs etc, resulting from an inadequate background, underdeveloped thought structures etc, has become most important in recent years. Excellent research reviews are already available as indicated earlier in chapter one. Teachers of physics, and of science in general, would do well to take note of this research, and accept that science teaching is not a matter of just passing on a ready made body of knowledge. Already models / strategies of science teaching to challenge these problems have surfaced, for example the conceptual change strategy. The model for conceptual change or replacement as presented by Posner et al [1982] has four stages:

(i) essentially the student becomes dissatisfied with the the capacity of existing concepts to solve the current problems.
(ii) a new concept is presented in such a way that the individual is able to structure experience sufficiently well to explore its explanatory possibilities.
(iii) the new conception becomes plausible, in that it shows consistency with other knowledge and has the capacity to solve the problems left by its predecessors.
(iv) the extensive application of the conception shows it to have extensive explanatory and predictive powers.

Hewson [1985] has reported on the success of this method and emphasised that, on establishing the prior conceptions held by students, the dominant teaching strategies should be those that attempt to integrate new concepts with those that are already existing in the minds of the students. An instructional strategy broadly based on the conceptual change model causes a much better acquisition of scientific concepts than the traditional intergration strategy, [Perez 1985]. In a recent paper, Helm et al [1985] draw attention to the role of thought experiments in bridging the gap between existing knowledge held by students and that desired by their teachers, and stress the invaluable place of thought experiments in overall strategies in physics education.

Knowledge is not learned but constructed from a merging of the old concepts and those that have been newly acquired [Osborne & Wittrock 1983]. There must as far as possible be no intrinsically arbitrary relationships between new concepts and those that the learner has already assimilated.

> " The essence of the meaningful learning process is that symbolically expressed ideas be related in a non-arbitrary and substantive (non verbatim) fashion to what the learner already knows" [Ausubel, 1978]

Even more recently researchers have addressed themselves to the problems of assimilation [Otero 1985; Viennot, 1985], and to issues of cognition at first year university level on a broad attitudinal and psychological base [Calliot 1983; Champagne et al 1980; Larkin 1981; Reif 1981; Schmid 1984]; and also on the structural and orderly development and presentation of concepts [Jones et al 1981; Karplus, 1981].

More importantly and nearer home, researchers have looked at the simple circuit theory and tried to develop improved methods of presentation of the related subject matter for more effective conceptual learning to take place. Attempts have been made to clarify, elucidate and further develop the concept of electromotive force [Gardner 1980; Heald 1984; Peters 1982; Rose-Innes 1985], for example its modelling generally as a kind of electro-pump etc.

Quite legitimately the concept of electrical resistance has received some attention [Iona 1979; Johnstone et al 1978], and some popular models have been presented and analysed critically. There is scope for further development of the concept of electrical resistance since the popular models do not adequately deal with such questions as resistance being constant for a particular component or whether it is temperature dependent or not. Most of them rely on defining resistance in terms of Ohm's law.

Steinberg [1983], has elaborated a rather ingenious method for correcting specific inappropriate conceptions relating to the nature and "flow" of electric current. This novel technique makes extensive use of capacitors, but because capacitor theory is not an essential part of most present core syllabi in the schools, this method is not attractive for our local situation. Hartel [1982], and Evans [1979] in particular, and many others [Arons 1982; Iona 1979], have suggested that the electric circuit should be looked at as a system, and have validated the approach of using experiments as a teaching strategy. Students should do experiments with d c circuits and observe the measurable quantities. Johsua et al [1987] argue that the field of physics functions in the hypothetico-deductive model and that the direct handling of materials, the observation of phenomena at work, and the practice of measurement can provide a natural way for students to discover the laws of physics.

Activities involving simple direct current circuits, using batteries and bulbs (and hands on experience) have proved in this research to be a most powerful instrument in uncovering alternative conceptions that students have and I have accordingly used this technique with great success (I think) in the attempts to correct and accommodate inappropriate conceptions. This will become clear as the chapter evolves.

5.2.0 General Implications for Learning:

In addressing the conceptual difficulties of first year students there are a few different approaches we can use. Some of these have been highlighted in the last paragraph. Of course it would not be possible in a limited effort like this one to address all the issues featured in the last chapter, as some of them can not be attended to directly. However, in trying to resolve any single specific problem which has been identified, I have looked at it in terms of the students who have presented themselves to my first year classes in the past few years. There are a few specific suggestions that I would venture to make in relation to the teaching of electricity, in view of the findings of this research.

A fundamental view is that new concepts and principles must be presented in such a way as to develop links with the most stable and inclusive ideas in the cognitive structure of the learner. Thus, we can easily understand the importance of taking into account the student's intuitive ideas, prior conceptions and alternative concepts; his primitive assumptions on the issues involved especially with regard to his assumptions on the nature of knowledge. Concepts in science should be presented as a response to an outstanding problem. A criticism of science courses and school textbooks is that they do not provide students with the problems which the new concepts came to solve, but instead with answers, that is, explanatory concepts and principles [Otero 1985]. Teachers should attempt, even if in a limited way, to provide for this, by for example laying out / providing laboratory activity.

In addition, as instructors we must take cogniscance of the fact that first year students tend to think of scientific knowledge as only a catalogue of facts in which there is no underlying need for conceptual unity. This problem/outlook is perpetuated by the approach of most textbooks and teachers, not only at the school level but also at tertiary level. Here scientific knowledge is invariably taught, and consequently viewed by students, as a valuable collection of facts, principles, rules and logical statements. The outlook that is perpetuated, mainly at the schools' level, that science is a set of formulas / (unrelated) strategies to solve/explain secular problems is an unfortunate and limited perspective. This approach "mitigates" against a scientific attitude. Students will tend to use the single bits of information to only solve local issues and look back to the bank (teachers) for more tricks, and rules of thumb, to solve any other isolated problem. In this way nothing has to make sense at all and "results" are used mechanically.

There is now general agreement that such a static view of knowledge is of very restricted utility in science, in all contexts of a more than routine nature. In this country the system of specific prescribed syllabuses and national examinations perpetuates this problem. So does the problem of shortage of qualified teachers in the black schools. It is just about the only method an underqualified teacher will use to teach. By contrast science should be viewed as more dynamic and as emphasising the flexible use of knowledge. Predominant interest in the classroom would then be focussed on processes whereby limited information can be used adaptively with situations that may be more complex or novel, emphasising the ability to solve problems.

As teachers we have to continually monitor what inappropriate conceptions the students bring to the lecture room situations, what incorrect conceptions they may bring forward as a result of interaction with the environment, their parents, peers, the media, television, newspapers etc;.

I will give here a couple of examples which I think illustrate this starkly in the case of electricity.

Example 1:

The first one is an extract from a newspaper report (Eastern Province Herald March,1987) about an event of very significant scientific interest. As a result young impressionable students of physics would be very attracted to the report table below :

U S breakthrough for cheaper power

WASHINGTON: Physicists have achieved a breakthrough in superconductivity research that points to dramatically more efficient and cheaper electrical power.
The researchers at the University of Houston and the University of Alabama, have achieved superconductivity -- the ability to transport electrical current with no resistance -- at a temperature so high that it could be called a breakthrough, said the government's National Science Foundation.

The researchers reached superconductivity at -175 degrees below zero Celsius. The measurement is almost 37.8 C warmer than the mark set two months ago.

When superconductivity is achieved electricity can travel further with greater efficiency.

After its discovery in 1911, scientists believed superconductivity only occurred when materials were kept close to absolute zero, or -272 C the temperature at which the normal motion of molecules ceases.

For decades, researchers have experimented with new conducting materials and techniques in attempts to raise the temperature where cheaper and easier-to-use coolants could be employed for practical uses.
Teams headed by Mr Paul C W Chu at Houston and Mr M K Wu at Alabama finally surpassed that threshold.-- Sapa A P

I would like to draw attention to a couple of statements in this article:

(a)

"The researchers have achieved superconductivity

-- the ability to transport electrical current with no resistance --

at a temperature so high that it could be considered a breakthrough"

Comment:

(i) In the physics sense it is misleading to talk of transporting *electric current* when current is actually evaluated at a point

Later in the report:

(b)

When superconductivity is achieved

--electricity can travel further-- with greater *efficiency*

Comment:

(ii) It would also not be clear what is meant by 'electricity can travel further'.

A student's mind would try to establish what this 'material' something, which actually moves from one place (source) to the other (point of consumption), is Very likely the student would be trying to figure out whether this is electricity the "energy" or electricity the "current" or what?

And he would essentially be incorrect each time as both current and energy cannot actually be measured and found to be less after the point of *consumption.*

Example 2:

This example involves an advertisement which is put out by ESCOM: The Electricity Supply Commission [1987] - a semi state body. The advert has appeared regularly in the popular press read by black people in 1987, for example in the Johannesburg paper, the "City Press".

It involves the picture of a man (Mr Simon Mahlangu) carrying a car battery on his head and advertises the promise that the convenience of electricity / power will one day get to his township:

I have depicted this picture below.

"Being without electricity is getting heavier all the time"
...Simon Mahlangu

They say that watching T V makes you lazy. But that's not when you have to carry the electricity for your T V yourself. So you keep watching the people who put up the power lines and hope that one day there'll be one leading to your house.

Escom would like to bring the light, warmth and entertainment of electricity into every home in South Africa. And in most areas, we already have the electricity waiting for you.

But there is a vast amount of work to do first. Cables have to be laid to carry the electricity into your home, and every home has to be wired to receive that electricity.

The caption reads (in part) as follows:

"Being without electricity is getting heavier all the time .. ...."

"They say watching television makes you lazy.
But that's not true when you have to carry the electricity
for your T V yourself .. .. ..

C o m m e n t:

Again it would not be clear what is meant by electricity in this situation; whether it is energy or current or something else which is being carried.

It certainly makes one suspect that Mr Mahlangu is carrying some 'physical' electrical energy pumped full into the battery; which will be poured out when his TV is connected

5.3.0 The Main Approach to tackling the problem:

In my attempt to address the issues I have categorised the problems broadly into two areas. In the first place I have dealt with those aspects that pertain to the presentation of specific subject matter, elements of the instructional procedures. I have suggested how specific topics / concepts should be organised and presented into what I would hope are more meaningful frameworks and effective conceptual structures. I have then attempted to give some idea on how we have tackled the problem as it has presented itself, in the students who have entered our first year physics courses in the past five years. In so doing I have been mindful that they come from an intellectually inadequate background with implications for language and laboratory hands on experience. The first language of all these students is not English although physical science is taught in that language even at the schools level.

One of my suspicions was that the traditional methods of presentation of the theory were a circumstance where one could tackle this. Efforts can be made to present the broad theory in a perspective which is relatively more palatable to the students; one that will not lead naturally, and in an obvious manner, to some inappropriate conceptions.

The historical traditional approach is not always the best one especially for students who have a different background culture variation.

To give but a few examples:

(i) The historical approach has landed us with electromotive force -as for "force". --in the place of Energy (joules) per unit charge. In general the concept names are not explained to have special scientific meanings and not the ordinary everyday language meanings.

(ii) Electric current has played a far too dominant role, in the place of energy; because conventional presentation procedures of the theory are rather brief and hastily resort to making students do calculations on electric current.

(iii) The traditional emphasis that the energy "comes" from the battery is mind boggling for students who try to figure out how the electrons that are already in the conductor get this energy to keep/start moving on. It encourages them to think that all electrons/charges set out originally from the battery at the time the circuit is switched on. Current and volts are easily thought of as stored in the battery and as coming out of there to flow around the circuit.

Secondly I have suggested the use of practical work. One of the major setbacks of students entering university level courses, particularly at black universities, is that they have little experience with the phenomena they are supposed to study (in any scientific sense), and this is particularly true with the study of electricity. They come from homes and environments where they have not interacted even casually with electricity. It is a pedagogical truth that such experiences would normally provide an intuitive base upon which the more abstract concepts they will meet can be built. In addition, without concrete experiences students have difficulty in generating any interest and enthusiasm for the topics to be studied. The teaching process should provide these experiences before life world conceptual frames take over completely. The importance of concrete experiences has also been highlighted in other research [Semper 1982].

Most of the research that investigates in-depth students' conceptual understandings is conceived within the constructivist view of learning, knowledge and understanding. This particular research was also undertaken in this framework. According to this view learning and the growth of understanding involves the learner constructing or "generating" [Osborne et al 1983] his or her own understanding of some part of the public knowledge. Constructivists are interested in the well established idea that learner's prior knowledge is a sine qua non in constructing meaning; that the interaction between new knowledge and existing relevant (private and personal) knowledge is the most important ingredient in the process of meaningful learning.

The research on alternative conceptions has confirmed that there are basically two broad categories or knowledge areas which have to be looked at closely [Pines and West 1986]:

(i) The knowledge that students acquire from their interactions with the environment.
(ii) The knowledge that students acquire in a formal fashion through intervention in the school setting

The inappropriate conceptions and misconceptions of students which have been diagnosed generally come out of these two areas. I believe that they arise as students attempt to make sense of the various inputs of public knowledge. As a general approach teachers should give recognition and status to these students' conceptions, show appreciation and admiration for the creative abilities revealed by the students, and should accord them some respect. All our attempts should be directed towards remediating and accommodating these inappropriate conceptions.

It seems to me that a significant way in which the situation may be improved in the learning of electricity is to expose students to practical activities. These activities will introduce the frameworks of what actually happens and these frameworks will normally help to enhance the conceptualisation because of the evidence gathered from actual observations of the phenomena. Laboratory activities give the opportunity for the arrangement of controlled and modelled experiences. These can be achieved without much inconvenience in direct current electricity theory. These experiences and observations should normally be very effective to those students who have not had them.

This includes for example the majority by far of all the students from black schools where there is a minimal infrastructure for laboratory work at the schools' level.

In addition the situation in the laboratory is easy to monitor so that the expected output and results should materialise. The laboratory activities introduce the original motivation for the theory. In setting up the controlled and modelled experimental situations, we expect that these should be able to spontaneously bring up or raise in students' minds the kinds of questions which the acceptable theory attempts to explain. They bring back the excitement of discovery, and enhance enthusiasm.

I do believe that practical observations do in fact
i) confront and rectify incorrect conceptions directly
(for example that of 'current measured before a resistor
is not equal to current after the resistor') and

ii) set alternative conceptions into proper perspectives.

The resulting conceptions should certainly substitute the misconceptions which had been rote learned in the school situation from teachers etc. In this way practical activities act on alternative conceptions from both knowledge areas. The majority of research workers in this field support this proposition as has been indicated by the research reports cited in the literature review.

There is an additional strategy which I have used to confront the situation, very much in line with the conceptual change strategies which have been mentioned earlier:

Once one has become aware of and has established certain alternative conceptions and misconceptions in students, it is important to set out to remedy these; and to accommodate them directly once one has identified possible sources and origins of these. In my teaching I was mindful of the incorrect conceptions that the students bring to the classroom situation. I tried to explain word meanings and word names more explicitly. I would tackle the conceptions by integrating classroom demonstrations of certain experiments which correct the inappropriate ideas. For example current does not diminish along a series circuit: This could be done by *proving* during an experimental demonstration through measurement that the current at different points in a series circuit is equal.

The diagnostic interviews done earlier provided a starting ground for further sit down sessions with students where I could help them to formulate more appropriate conceptions through experiment demonstrations and argument.
I also looked out for (and generated situations) for opportunities where inappropriate conceptions surfaced spontaneously, during the first year physics course; for example during the scheduled experiments programme, during tests, etc. I then arranged meetings with these students so that we could deal with the incorrect conceptions.

In broader terms I was attempting to deal with the alternative conceptions in terms of the constructivist approach. The basis of the Constructivist view is that what a child brings to the learning situation is the largest single factor of importance, because he uses it in the equilibration of new concepts. To me it seemed very important to pinpoint the things he knows and how he understands them in the operational context. In that way the new infomation could be structured and presented in a form that will have meaning and from which the student can generate the new knowledge.

There is general support for this approach from experts [Duit et al 1984; Fredette 1981; Johsua et al 1987].

Some physical theories develop historically and spontaneously; they do not necessarily build up from the more fundamental to less fundamental concepts. They may very well raise some questions as they answer the others. I have illustrated this in the last paragraph. There is always scope and motivation to move on towards a relatively better suited approach cognitively, or maybe a conceptually ordered approach, especially when teaching the concepts to young minds.

I will use a very simple example to illustrate this.

Example:

Most university first year books have realised that it creates a problem in students minds to merely indicate the internal resistance of a battery in the way shown in Figure A [below]. The student is not encouraged to accept that a battery in a circuit is also a resistor, that in fact electric current also passes through it. Some authors have then moved on to the other forms of reinforcing this concept of internal resistance [see Figure 5.1 B and C below].

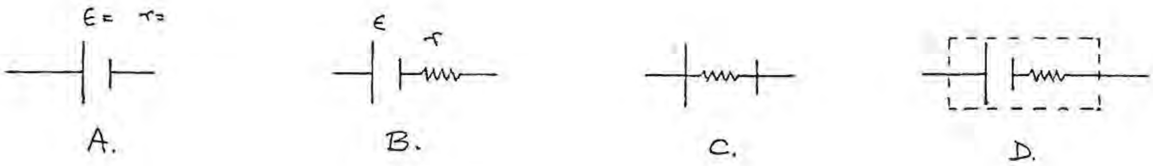


Figure 5.1

Recently I have noticed that Sears et al [College Physics 1986], have moved on to the form illustrated in Figure D in the latest [sixth 1986] edition. My students, using the fifth edition for the last five years, particularly had a problem with handling the symbol - as shown in C.; when applying Kirchhoff's rules especially in terms of the direction [sign] of the product Ir when compared with that of the emf E. I see the 'new' approach used by Sears et al in Figure 5.1 D. as an attempt to resolve this conceptual problem

I therefore found it important for me to cover the particular aspect of looking at how palatable the knowledge is to my students, in the form in which it is conventionally presented. Thus an approach in addressing the problem was to make certain proposals as to how the formal theory of direct current may be presented so that it will be more meaningful particularly to the types of students that I continue to teach. Hopefully in this way I would be in a position to obviate the occurrence of some of the alternative conceptions which I have come to be aware of.

In the proposals in this regard I have endeavoured to make specific suggestions, bearing in mind the particular inappropriate conceptions that I have found with my students over the years. I have had to be mindful of what I had perceived the major problems to be, and what I have diagnosed as students thinking errors; for example difficulties with words for concepts, concept of "potential energy", and "energy" in general as a physically observable form.

I set out to do this in the firm belief that established scientific knowledge at this level is tasteful to the students and that the efforts of correcting their inappropriate conceptions are deeply ingrained in the minds of students. I do believe that the tenets of the appropriate theory are not unrealistic and difficult to access; that in the long run they should survive the day in students' minds. In the final analysis students are ready and willing, psychologically and mentally, to be guided and channelled along towards closer encounters with it. Pines and West [1986] put it well:

> "The need to make sense of what one encounters seems to be a deeply ingrained human quality that is too often destroyed by the schools that make, or even encourage, meaningless rote learning as a legitimate goal. "

I will now discuss some of the teaching strategies and techniques which I feel would help the students that I have taught in learning satisfactorily some of the ideas related to direct current electricity circuits. An essential part of this procedure is to point out those presentations and procedures which I feel hinder the learning of appropriate concepts in the type of student that I have taught, and to indicate how we could deal with these. Bearing in mind particular tendencies for alternative conceptions to form around certain central concepts, I will propose certain instructional sequences and outlooks detailing how these sections of the work could be introduced to formal classes or small groups of students, so as to address the incorrect concepts. In the latter part I will set out how practicals were used to encourage more acceptable conceptions.

In addressing the issues I had to make certain decisions about the knowledge state, in d c circuit theory, of the students who enter first year physics classes at the university. The students who come to the University of Fort Hare to do physics courses come from various parts of Southern Africa, from different language groups. As Africans however the cultural and sociological common factors among these groups seem to dominate. Their schooling is similar since they come out of the black education system. The overwhelming majority wrote the same National Senior Certificate examinations [NSC] at the end of their last school year. Their grades in standard 10 Physical science would generally be very low, as indicated in an earlier chapter [chapter two].

5.3.1 What the syllabus prescribes:

The syllabus of the NSC indicates some extensive work in the sections on static and current electricity, including potential energy in electric fields etc,

Below I have extracted some relevant paragraphs of the core syllabus of the National Senior Certificate for standards 9 and 10 :-

AS FROM THE EXAMINATION OF NOV./DEC. 1976 Reprinted 1981

[A new syllabus has been effective from the examination of Dec 1987]

4. ELECTROSTATICS

4.1 Electricity at rest

Very briefly revise the former qualitative studies of charges at rest.
Principle of conservation of charge.

4.2 Force between charges

Coulomb's discovery that force between charges is inversely proportional to the square of the distance between them:

$$F \propto \frac{1}{r^2}$$

Sharing of charge between identical conductors. The discovery that force between charges is directly proportional to the product of the charges.

$$F \propto Q_1 Q_2$$

Coulomb's law in the form $F \propto \frac{Q_1 Q_2}{r^2}$

$$F = K \frac{Q_1 \; Q_2}{r^2}$$

where $k = 9 \times 10 \text{ N } m^2 \; c^{-2}$

Calculations limited to the force between two charges.

4.3 Electric Fields

The concept of an electric field.
Lines of field for a single point source; two point sources; a sphere and parallel plates
(Plates large compared with separation)
A charge in an electric field experiences a force; field strength (intensity) as force / unit charge.
Work done in moving charges in electric fields.
Potential energy of a charge in an electrostatic field.
Potential difference (in volts) between points in a field in terms of

$$\frac{\text{Work done in (Joules)}}{\text{charge moved (in coulombs)}}$$

The volt is considered as joule/coulomb.

Quantitative treatment of the field between parallel plates:
Strength of the field (E) $= \frac{V}{d}$.

4.4 Quantisation of charge

5. THE ELECTRIC CURRENT

5.1 Current

A current is a flow of charge.
Discuss the model for electrical conduction in metallic conductors.
To maintain a current in a conductor, an electric field must be maintained in the conductor and a continuous supply of electrical energy must be provided. A source of emf provides this energy.

This existence of an electric field in a conductor implies a potential difference across it.

5.2 Force on current bearing conductors
Observe force between current bearing conductors.

5.3 Magnetic field and its vector B

Discussion of the force between conductors in terms of the magnetc field concept:

5.4 Resistance and Ohm's law

Recall resistance in terms of potential difference and current

5.5 Heating effect

Point out that "heating" does not mean that the resistor receives heat but that its temperature increases as a result of electrical energy being converted into internal (thermal) energy.

Energy transferred to the conductor, $W = I^2\ Rt$ joules.
Show that the energy transferred is proportional to I to R and to t.
Recall power as work done per unit time.
Unit of power: watt (W), ($J.s^{-1}$).
The volt defined as watt per ampere.
Simple calculations.
Emf (E) now considered as the rate of supply of energy per unit current.

$I = \frac{E}{R + r}$ for a simple direct current circuit consisting of a source with an internal resistance r. and an external resistance R.

5.6 Alternating current

6. THERMIONIC EMISSION

My impression is that the concepts to be attended to are clearly stated in this syllabus, and if it is examined closely, users could go a long way to focus in the correct way on the underlying conceptual links. Some real and practical difficulties might still be experienced with it, by teachers who are not sufficiently comfortable with the concepts (eg underqualified teachers). These problems may be made worse by any statements in a textbook that tend to give incorrect impressions about the conceptions involved.

I am a little bit uneasy about the title of paragraph 4.1 which is "Electricity at rest"; as it may suggest that in the paragraph 5.1 we are dealing with electricity which is not at rest, ie that current is electricity which is moving. The word "electricity" seems to me to be a life world word which has no real conceptual basis in physics beyond being the embodiment of all knowledge connected to the study of situations/aspects related to stationary and moving charge.

Also, the NSC syllabus in paragraph 5.1 defines current as the flow of charge. One would be happier if current was defined as the rate of flow of charge through a surface as I am certain this was what is meant. The former might imply [to some teachers who use the syllabus] an actual flow of a substance *current* from some point (-ve electrode) to some other point (+ve electrode); and they might fail to understand that electric current flows everywhere in a closed electric circuit. The impression might be that electric current has a place of origin and of destination in a d c circuit; and that -ve charge is created at the -ve electrode and destroyed at the other electrode.

5.3.2 Some comments on what some textbooks say:

Below I have extracted some excerpts from textbooks which are currently used in the schools and which follow this syllabus. This I hope, will give some idea of how the syllabus is interpreted by some textbook authors.

As expected these books introduce current as a flow of charge.

(i) .. .. an electric current is a flow of charge

[p128 Brink & Jones Std 9 Juta 1977 and 1981]

.. .. the flow of charge (..) from one point to another is called an electric current

OR

.. .. charges in motion constitute a current

[**p 71 Brink and Jones Std 8 Juta 1986 [New syllabus]]**

(ii) .. .. the continuous flow of charges is called an electric current

[p 111 Meiring, Getliffe, Pienaar& Walters Std 8 Nasou Ltd]

(iii) .. ..the flow of charge is called an electric current

[p169 Std 8 Pienaar & Walters Maskew Miller 1973, 1976]

(iv) .. .. the charges which are free to move will do so and they |become| the electric current

[p 76 Broster and James: Successful Science Std 10 New Syllabus. Oxford University Press 1987]

(v) .. .. the current through the electrolyte is a movement of negative charges towards the anode and a movement of positive charges in the opposite direction towards the cathode, whilst the current in the metal of the outer circuit is known to be a flow of electrons.

Note that the electric current through the electrolyte is |carried| by negative as well as positive charges

[p 161 Gordon, Neser, Pienaar and Walters std 9 and 10] Maskew Miller 1973

I would hesitate to claim that there is anything fundamentally incorrect with the explanations given above in so far as they may lead to a better understanding of the nature of current. The intentions of the authors are good, and they perhaps perceive that as a strategy this approach is useful. It seems to me that in terms of generating incorrect conceptions the potential is greater with the approach of explaining current as movement of charge and current strength as the rate of movement of charge. There is only one concept involved here. Whilst it may be true that where charge flows there will be electric current [or current happens], I take the standpoint that it is more appropriate to emphasise very early that electric current is the rate of flow of charge through a surface or point.

Where there are resistors in parallel and series and an equivalent resistor has to be calculated, some of these books refer to the 'total current' of the circuit. To me this may give the impression that the current is supplied from the battery and flows in time through the various branches of the circuit. I see a benefit conceptually in thinking of current as an event at a point/surface in a circuit.

An additional complication is that some of the textbooks almost treat 'current-strength' as a separate concept from electric current.

(vi) .. .. the current-strength is the |amount| of charge
that passes a particular point in a circuit in one
second

[p **Broster and James std 8 1985]**

(vii) .. .. the strength of an electric current is measured
in amperes and is a measure of the rate at which the
|electrons| are flowing [why not 'at which the charge'?]

[p 72 **Brink and Jones std 8 1985]**
An electric current is merely a flow of electric charges.. .. .. ..
The CURRENT STRENGTH is the amount of charge that flows past a point in a conductor during unit time

[p 94 Physical Science for Standard 9 and 10
Bowen and Roberts Southern Book Publishers 1987]

Most of the books that I have looked at are arranged well and describe concepts adequately in some parts. They cannot easily be faulted for encouraging incorrect conceptions through direct statements they make. Some of them even embrace the philosophy that an electric circuit is basically a system in which energy is exchanged/ transferred and not used. It can be argued though that some of the extended explanations (insinuations) elsewhere in the same texts could lead often to an incorrect understanding of the underlying concepts. From using these books, teachers who do not have an adequate background [unqualified] could pass on incorrect ideas to the students they teach etc;.

I will indicate briefly some of these statements . To me the quotations illustrate dramatically that certain student conceptions, which I have identified, are directly related to the textbook statements. This should be expected because most teaching in Southern Africa takes its authority straight from the prescribed textbook.

Some of the books use the approach that (-ve) charge [and hence current] originates / comes from the electrode and is taken off at the other electrode; and do not address directly [conceptually] the idea that charge [and hence current] does flow through the battery.

My assessment is that there is a definite advantage conceptually in thinking of current as flowing through the battery as well, and I have tried to illustrate this in the sections that follow.

Examples:

(viii) .. as soon as the conductor is connected between the terminals of the battery, electrons provided by the battery at the negative terminal begin to move through the conductor towards the positive terminal.
[What about electrons which are already in the conductor?]

p 182 Pienaar and Walters std 8

.. .. the same quantity of charge can be transferred from one terminal of the battery to the other when a weak current flows for a long time or when a strong current flows for a short time.

[p 172 Pienaar and Walters std 8]

(ix).. The function of a cell in a circuit is to provide high energy electrons at one terminal and to withdraw low energy electrons at the other end continuously.

[p128 Brink and Jones std 9]

AND

.. since electrons are supplied at the negative terminal and withdrawn at the positive, there is a continuous flow of electrons from negative to positive.

[Brink and Jones std 9]

(x) .. it means that a fraction of a second passes from the moment that an electron enters one end of the wire until another one emerges from the other end. [how about simultaneously?]

[p 111 Meiring, Getliffe and others]

The explanation that electrons come from the negative electrode would encourage some students to think that there are normally no electrons in the conductor.

In line with the requirements of the syllabus, an energy framework is followed by most books in dealing with the electric circuit. This is reasonably set out in some parts of the textbooks; although, in my opinion, the established ingredients are not exploited fully.

In parts some of the statements may be confusing:

.. .. the total amount of |work done by the battery| in moving one coulomb of electrons from A to C [in the circuit]

[–A—ʌʌʌʌ—B—ʌʌʌʌ—C——> direction of current]

may be considered to be in two parts, A to B and B to C

[Brink and Jones std 9]

.. .. the fact that the electrons move move from the negative to the positive terminal indicates that the negative terminal is at a higher potential than the positive.
* [this will definitely have to be modified later on]

(xi) A source of electrical energy such as a cell, battery or dynamo supplies energy to the |charges| in a conductor so that an electric field is created which in turn causes a current to flow in the conductor.

[p 149 Active Physical Science std 10 [New Syllabus 1988] Muller, Muller Dreckmeyr and Dal Bianco]

Inappropriate conceptions may be encouraged by certain of the extended explanations; for example, from the statement in (ix) in the last paragraph students are likely to infer that the potential energy of the electrons manifests itself in some visible mechanical way; that the energy is possessed by the electrons in some obvious physical form since the electrons are referred to as "high energy" electrons. Also, in suggesting that each charge or electron receives [electrical potential] energy as it passes through the battery from it, there in an additional problem in explaining how the electrons which are already in the conductor at switch on receive this energy.

also

(xii) " the emf of the cell is the amount of energy that the cell is able to *give* to one coulomb of charge passing through the circuit.

[page 128 Brink and Jones Std 9]

(xiii) .. A source of emf does not produce charge, but it gives electrical potential energy to the charges passing through it. .. As charge flows in the circuit it loses electrical potential energy which it gained from the source.

[p 76 Broster and James: Successful Science Std 10 [new syllabus 1988] Oxford University Press 1987]

(xiii) Problem set in Std 8 book by same authors: What is the potential energy of 3 coulombs of charge leaving the battery?

.. the potential energy that is lost by the |**current**| in the connecting wires is so small that it can be ignored

[p58 Broster and James Std 8: [new syllabus 1987]

We must now investigate the work done by an electric current in a conductor .. ..

When an electric current loses electrical potential |energy| in a conductor,the energy changes that follow do not always result in the heating effect.

[p 96 Broster and James: Successful Science Std 10 [new syllabus 1988] Oxford University Press 1987]

(xiv) .. The cell, if charged, is a *store* of energy which can do the work of moving an electric current through a circuit [moving an electric current??]

[p 169 Pienaar & Walters std 9 and 10 Maskew Miller 1979]

The last quotation indicates strongly that there could be some difficulties with the concept of electric current which is really the *rate* of passage of charge through a surface, and thus does not move from point to point in the circuit. Below I have given further examples of how students can be misdirected by what is written in textbooks into thinking that current is supplied by the battery in the sense that it originates from there; as a "substance" that is given by the battery.

(xv) .. .. we can control the electric current and harness it for our benefit. We can *take current* where we want [by conductors and wiring]

[p 75 Broster and James:Successful Science Std 10] [new syllabus] Oxford University Press 1987

"The arrangement [of four cells in parallel] does have the advantage that each cell has to *supply* only a quarter of the current in the main circuit"

[p Broster and James: Std 8 1985]

(xvi) .. A flashlight has a high internal resistance, hence it cannot supply very strong currents to the circuit outside the cell. A motor car battery has very low internal resistance. and very little current is |wasted| inside. The battery can *supply* a very strong current to a circuit.
[p 182 Pienaar and Walters std 8]

There must be at least one other parameter eg size of electrodes which is involved here as well. The supply of current would indicate that it leaves the battery to be used elsewhere. My students would not underst and how a current which is supplied by the battery still passes through the same battery.

(xvii) " Simple experiments to show that static electricity and current are not different electricities p 157

.. the two electric currents experience a force in each others magnetic fields.

currents in the same direction attract; currents in the opposite directions repel p 195
[how can a current repel?]

[Gordon, Neser, Pienaar and Walters Maskew Miller 1973]

Also, an incorrect conception of resistance may be got from the passage below:

.. Electric charges do not move by themselves [in an electric field?]; a force must act and work must be done in moving a charge through a conductor, as all conductors (except some at very low temperature) resist the flow of charge.

[p202 Gordon, Neser, Pienaar & Walters Maskew Miller 1973]

The impression some students would get from this line is that : Work is done on a charge in an electric field only because there is something resisting the flow of charge [a resistance to oppose].

The link between particular inappropriate conceptions and the books used by the students cannot be established more firmly. This was not the intention of this short treatment above, since I did not know

(i) if the students who had manifested the incorrect conceptions had used certain particular textbooks or

(ii) how their teachers had interpreted and presented actual concepts.

At the least these quotations indicate the potential of textbooks as a source of inappropriate conceptions.

The NSC syllabus offers an excellent approach in terms of treating the electric circuit as a system in which the energy is exchanged.

Illustration:

In paragraph 5.1

" .. To maintain a current in a conductor, an electric field must be maintained in the conductor, and a continuous supply of electrical energy must be provided. A source of emf provides this energy. "

and also in paragraph 5.5

" .. Emf (E) now considered as the rate of supply of energy per unit current"

In my proposals I will attempt to exploit this approach, as I see minimum real advantage in looking at the electric circuit as a system in which electric current is the leading concept rather than the concept of energy.

The parts on "electricity at rest" are generally set out well in many books used at school and my impression, even from the interviews, is that high school graduates have little problem with the fact of repulsion and attraction of charge in the neighbourhood of other charge. The syllabus indicates that they have dealt with physical situations involving a charged particle in a constant electric field in terms of an electrical force acting on the charge [$F = ma = q E$]. In the interviews I found that students are comfortable with the concepts relating to the transfer and flow of charge as long as the charge was carried by a particle especially if the particle is an electron. What seemed to be important was that the latter can be dealt with in terms of mechanics [F =ma =qE] etc, and my perception was that students relate well to thinking in terms of particles.

However, I did sense that there were some difficulties in separating conceptually the shift or movement of charge from the actual movement of electrons. Hence they could not deal easily with current by thinking in terms of charge only but in little bits of charge carried by electrons. In addition, in an earlier chapter I have indicated that some students may have some problems on how Newton's third Law affects the magnitude of forces between any two charges. Students are also not comfortable with concepts of potential energy of a small charge near another charge as well as in a uniform electric field.

Since the main thrust of the research relates to concepts around d.c. electric theory, I felt that it was important to address the issue of the electrical potential energy of test charges especially in a uniform electric field.

Having taught in the schools for more than six years, and because of my associations (through Workshops, Seminars etc) with science teaching in the Black schools in South Africa for more than 20 years, my wisdom told me that I could not assume that the students knew expertly all what was listed in the syllabus. The student interviews also indicated that teachers generally avoided rigorous treatment of the underlying theory. My attitude was that they had been exposed to some d.c. electricity theory, electric fields etc; and were familiar with some calculations involving V=IR in d c circuits.

Bearing in mind this, and the very important issues discussed above in relation with the syllabus, I had a fairly good idea what the conceptual issues were that I had to address in connection with students who enter first year university courses in physics. As this investigation has revealed, these are largely issues related to notions of current flow, and the "use" of electricity [current] in simple circuits. The best way to start was to assume at least the incorrect conceptions which they brought with them; and which I had diagnosed. I was more certain of these inappropriate conceptions than anything else. All evidence suggests that students certainly do have very definite intuitive ideas of how d.c. circuits operate. I did not have to push them to come out with the inappropriate conceptions.

From this assessment a common approach evolved, and I decided on what seemed to me to be the best approach to use to teach d.c. theory to first year physics students. This is detailed in the paragraphs that follow.

5.4.0 Specific suggestions for the teaching of electricity:

Electricity theory of simple circuits, including concepts of charge and its flow in "resisting" media and conduction, ought to be taught formally in the school if it is going to be used indirectly at all. Central in this is the role of the electrical conductor, its property of "resisting" the current and the role of the cell (battery) as a "supplier" of energy. At the earlier levels of school teaching a more practical approach of "experiment and determine the result" should be adopted, leading to the cataloguing of the results and determination of behaviour patterns, in order to provide experiences. These controlled experiences will back up and "re-inforce" the theory which will be developed and unfolded in the higher classes.

Quite early at school level observations should involve determining current and potential difference using laboratory experiments. The effects, for example, of putting cells in series and parallel, resistors in series and in parallel, as well as shorted circuits can in this way confront the students before the more elaborate theory is presented.

I have charted below a scheme which could be used in doing this:

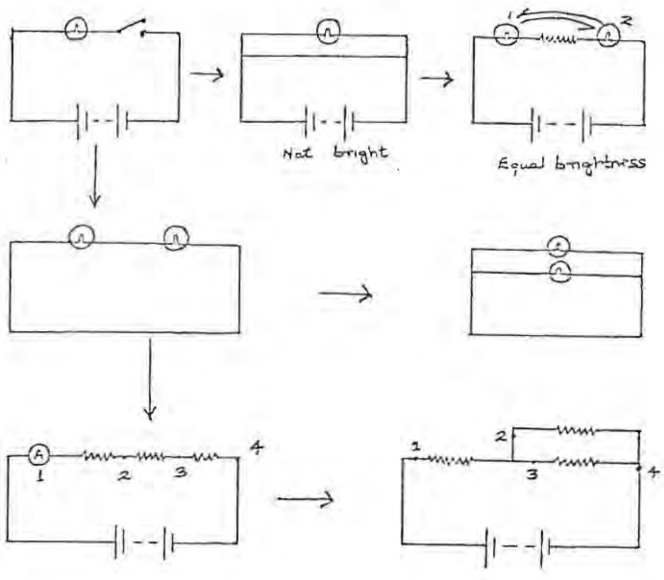


Figure 5.2

Students should be given practice in connecting a simple circuit of battery , bulb and a switch, and assisted to represent this in terms of a diagram. Later on, they should be able to assemble and draw simple circuits of two and three bulbs in series, and to determine the current at every point in the sequence indicated. The brightness of the light bulbs could be used to indicate the current in a circuit component, for visual emphasis and more effective impact rather than a voltmeter. The idea of an electric current occurring at a point should be emphasised. The potential difference across each resistor could be measured using a voltmeter and related to the p d across the battery. There should be thorough familiarisation with circuit elements including such apparent trivia as examining the parts of light bulbs, switches etc. The experiences should set out the terms which will be used in the acceptable direct current electricity theory to be elaborated on afterwards. The formal conceptions will then be presented in response to an outstanding problem resulting from the systematic observations and analysis of the catalogued observations.

It is important to present to students early what one might call "laboratory" electricity in order to obviate /circumvent the influences of life-world experiences in electricity which, one has to admit, present themselves relatively early and strongly in the life of the child, and may result in incorrect conceptions. The drill outlined above will at least make it easy for students to accept that electric current is not "used"; does not diminish after passing a resistor.

My assessment is that high school teachers avoid teaching the formal theory, for example, conduction through metals via movement of charge, electric fields and the energy relationships involved here. The phrase p.d is used routinely but is seldom, if ever, developed as p. *energy* d. School teachers spend little time on the section on electricity in general, and on the main prefer to play around with manipulations of Ohm's Law (the rules, tricks, again), with series and parallel resistor formulae, and approach 'electricity' in terms of "uses" of it like heating and lighting. The questionnaires and interviews with students have confirmed these suspicions. External examinations in standard 10 tend typically to ask fairly predictable short questions; and this style suits those students who try to remember isolated facts and techniques. In this way examiners also encourage rote learning.

Energy as a central concept to the electric circuit theory should not be avoided here. Care should be taken that students do not regard the generalisations / summary of the theory as unrelated and isolated in the scheme of thought.

One has to be mindful that the Mechanics theory from that section of the physics course does not lead naturally to the theory of simple circuits. In electricity students for example are not dealing with particles (eg. charges) whose movements they can observe and manipulate. In fact students in this situation are often misled in that they tend to interpret all energy situations in terms of kinetic energy because of motion.

Traditionally at school and in the first two years of university, teaching is through the use of illustrations which are anchored in the observable results of change in the physical world. A physical problem is considered to be solved if it is explained in mechanical terms. Students tend to view all systems and explanation using this outlook. It is my submission that energy and its flow in the electric circuit context cannot be satisfactorily treated in this totally atomist way. Charge and its flow cannot be understood fully in this frame either. It does not help much conceptually for students to think in terms of speeding single charges moving from one point to another but rather in terms of nett drift of charge.

As indicated in the last chapter, the majority of students are not familiar with energy exchange between atomic energy states (resulting in light emission) and prefer to think of the light energy and heat as generated mechanically through the actions of friction of the particles in the conductor causing heat and sparks, hence light emission. In error students necessarily look out for particle kinetics during charge movement. They are also not able to master potential energy at all as a conceptual construct. A much broader conception of energy flow and charge flow, one that is not necessarily atomistic, needs to be developed in their minds.

In the paragraphs that follow we indicate an approach to the teaching of electricity at university .

5.4.1 The Electric field: Concepts of Flow and Energy:

5.4.1.1 Concepts of Electric Current Flow:

It seems useful to start by explaining the concept of electric current . An underlying cause of most students' incorrect conceptions is aligning electric current with electric energy. There is a lot of confusion about the nature of electric current and I consider it extremely important to clear this up right at the beginning. Electric current may be described as the instantaneous rate at which (positive) charge passes through a surface . See Figure 5.3 below;-

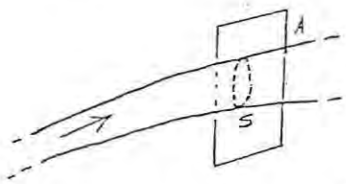


Figure 5.3

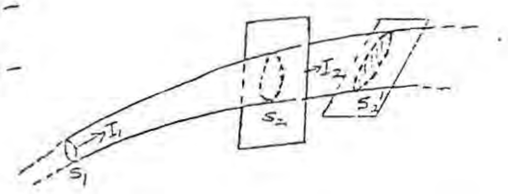


Figure 5.4

The figure shows a surface S that intersects a conductor through which charge is flowing . The electric current through the surface S is equal to the rate dQ /dt at which charge passes through the surface S.

That is $I = dQ/dt$

There is no need to mention electrons, protons or any other charged particles as moving through the conductor. Neither is there a need to mention a value for resistance R for the conductor.

Therefore the dimensions of current will be charge per unit time. The units are coulombs per second.

The situation represented in Figure 5.4 illustrates the behaviour imposed on the flow of current by the law of conservation of current and charge.

If I represents a steady current, no charge can accumulate in the volume defined by the surfaces S2 and S2', and the conductor wall. Therefore the electric current as determined at S1 is equal to the electric current as determined at S2. [I1=I2]. Moreover, the surface S2 may be replaced by any other surface S'2. whose perimeter is everywhere in the conductor wall, without affecting the value of I as determined at that surface.

I1= I'2= I2 ---------(1)

In the situation in Figure 5.5 below the current is observed/indicated in two parts; (I2 and I3) at different parts of the conductor, that are directed in two different directions. As a result I2 and I3 flow in different strands of the conductor.

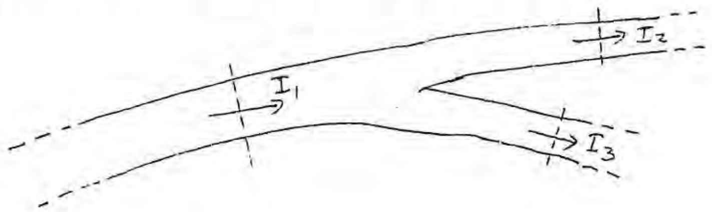


Figure 5.5

If the current is steady, then charge conservation requires that

I1 = I2 + I3 --------- (2)

The current in a closed circuit is always a steady current. No charge accumulates at any part of the circuit. It is important to stress that the two stipulations (1) and (2) are governed by this continuity condition and the conservation of charge principle.

If the current as detemined at a point is caused by the flow of (molecules of) water then current could be measured as the rate at which the water is passing that point; in kilogrammes of water per second or cubic metres of water per second. If the current is resulting at a point because of the flow of charged particles (for example electrons), then the electric current could be measured as the rate at which charge (carried by electrons) flows past that point per second. Thus the current, as the rate of flow of charge, is determined by ascertaining at least two things; the speed with which the charged particles go past and the number of particles (and amount of charge on each one) flowing past. It is never fully determined by considering just one of the above. Electric current is never determined on just the speed of the electrons or just the number of electrons going past a point.

The above explanation should help later on with the incorrect conception about electric current being unequal along different parts of the same series circuit and on either side of a resistor. It should also assist students to conserve matter, such that no electrons or any other form of matter or charge may be lost as it flows along a continuous conductor. At this stage we have not said anything about energy transfer, resistance, electric field etc. In a sense this is how far the model is similar to that of water flowing along a pipe.

There is an advantage in starting with the definition of electric current and its flow. It is a fundamental concept to simple d c circuit theory. Firstly it is reasonably free of the other concepts of resistance, energy, potential difference to which it will be linked later. Its explanations can be understood independently. It also introduces a frame of looking at the other concepts mentioned. The student has learned that electric current is not a substance, but an event or occurrence at every spot in the circuit. By fixing the meaning of current as an event / occurrence at a spot we minimise and discourage associations with actual movement in this or that direction, which he might be inclined to make. He will have less difficulties in understanding that electric current is not stored in the battery, and does not set out from there. Instead of emphasising movement and of transportation, we stress the direction (orientation) of electric current. The advantage of assigning at the beginning the correct category seems to be an epistemological one. The concept is introduced as what it is, a frame asking to be filled in by empirical investigations [Duit 1984].

5.4.1.2 Electric field and Concepts of Potential Energy:

In the conceptual model I would like to use, an electric field is set up in the conductor, because the conductor is connected to the positive and negative ends of a battery. There are many ways in which an electric field may be set up in a conductor. Students will easily understand that an electric field would be set up whenever there is charge separation. There will be an electric field between the two electrodes of a battery. Work has to be done to effect charge separation and set up an electric field , since unlike charges have a natural tendency to attract each other. A charged particle would be affected by an electric field in whose presence it is, in a similar way as a massive particle will be affected in a gravity field. The force that will be experienced by a charged particle in an electric field may be represented by

$F=qE$, where q is the charge on the particle,

E the electric field strength.

The example of the electric field between two oppositely charged parallel plates may be used here.

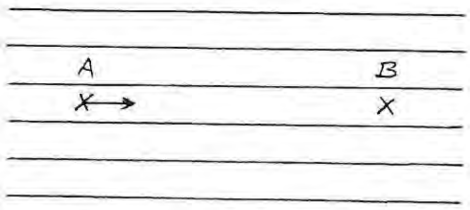


Figure 5.6

Let us assume that a positive charge q+ is momentarily in the field in position A (see Figure 5.6). This positive charge q+ will experience a force F= +q E because of the field of intensity E and will tend to move in the direction of the field, if the particle was at rest, as indicated in the figure above. It will accelerate in the direction of the electric field.

There are certain aspects about the electric field and (electrical) potential energy that need clarification:
Because work is done in setting up the electric field initially, there is already associated with the electric field a certain amount of (potential) energy.
If a positively charged particle (proton) is introduced into the space of the electric field [near the positively charged plate, if we have to think of the electric field as occuring between two oppositely charged plates], additional energy is given to the field. If the particle now is released at position A it will naturally accelerate in the direction of the field and acquire energy.

$$qE\,(AB) = \frac{1}{2}mv^2$$

Using field language we would say it acquires (kinetic) energy at the expense of the electrical potential energy (stored) in the field.

Another way of putting it would be to say, associated with the positive particle at position

A is (electrical) potential energy. This potential energy is larger than the potential energy that this same particle would have if it were at position B. The potential energy of the positively charged particle at position A is greater than the potential energy of the particle at position B by an amount of energy whose magnitude may be expressed as

$\frac{1}{2}mv^2$ or $qE(AB)$

The particle with charge would have a potential energy associated with it at every point in the field when compared to when it was not in the field.

I define here a new quantity called the electrical potential at a point in an electric field. The electrical potential at any point C in the electric field is the potential energy per unit charge of a small positive test charge q' placed at the point.

$$\text{Electrical potential (V)} = \frac{\text{Electric potential energy}}{q'}$$

It is important to note that, using this way of looking at things, with every point in the field will be associated a potential V; which is independent of the charge which may be present at that point. Therefore between any two points in an electric field there will be a potential difference, a potential *energy* difference per unit charge. This is the quantity which is normally called p d in relation to resistors in a circuit. The charge q' is normally a positive charge.

In general a free positive charge will drift in an electric field between any two points A and B if there is a p d [potential *energy* difference per unit charge] between them; and some energy will be exchanged. A positive charge would tend to drift from A towards B whilst a negative charge would move from B towards A.

In the situation described earlier where there is an electric field in a conductor, the positively charged particle momentarily at A will drift in the general direction of B because position B is at a lower potential than A [there is a p d between A and B]. When this particle is at position B momentarily, it will not possess ALL the energy [of magnitude qE(AB)] mentioned earlier as its kinetic (or other) energy. It will have collided several times with the relatively stationary particles of the conducting medium (in the lattice points) in its path, during the movement from A through position B [This will be explained more fully in the next paragraph]. In general some part of the energy will have been passed to the fixed lattice ions of the conducting medium during the collision.

Thus it is important to note that although there is a (electrical) potential energy difference between the points A and B there would not necessarily be a kinetic energy difference, especially of the magnitude qE(AB), between a charge carrying particle at one of these two points and the other at the second point. In fact it may well be that the particle at A has a larger instantaneous velocity than at B. The Figure 5.7 in the next subsection sketches the probable path of an electron through a metal conductor, through the points A and B.

5.4.1.3 Electric field and Concepts of current flow :

Students should normally be familiar with electric current and conduction theory by the final year of school/ standard 10. The approach of an electric field and atomic processes in the conductor could normally be used. There is no single way of tackling this task. However, a convenient starting point is to consider the cell (battery) as a device whose function it is to set up and maintain an electric field in a conductor. One way this may be realised inside the cell or emf source, is by charge separation. Whatever the way, there would as a result be a constant electric field maintained throughout the conductor. Charges within the conductor would then experience a force because of this field (F=qE), and would drift or tend to move, in the direction of the field (if they are positive and vice versa).

A model for electric current conduction :-

In a conducting wire such as illustrated in Figure 5.7 the atoms of the conductor remain in relatively fixed positions. So, the only charge carriers are the free electrons.
Let n be the number of free electrons per unit volume. If the wire [a resistor] is connected directly or indirectly to the terminals of a battery an electric field would be imposed on the wire. Suppose that the electric field in the wire is such that a conventional current flows to the right. In addition to their random motion, the electrons experience a steady drift to the left in response to the electric field. In the diagram following, we have indicated the path of a typical electron in its drift towards the left.

Motion representation of charge carriers [electrons] accelerated by the Electric field:

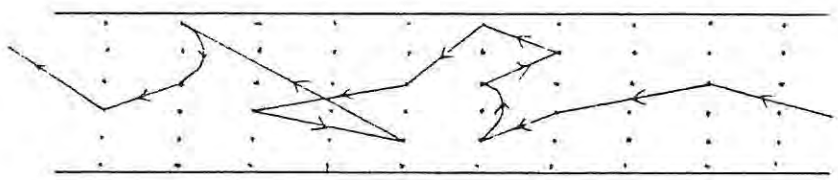


Figure 5.7
[From Iona, 1979]

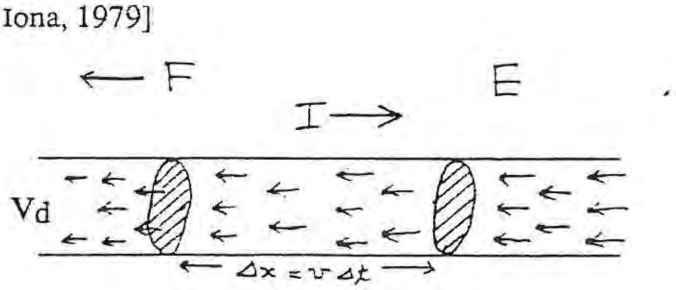


Figure 5.8

In the model it is supposed that some of the electrons [conduction electrons] are detached from their parent atoms and become free to move within the conductor much the same way as an electron gas. The electrons are imagined to move within the material and to collide frequently with the lattice structure of the material. Between collisions the electrons move in accordance with the force produced by the electric field qE. It is important to note that as the electrons drift they do not all have the same velocity. Some might be actually bouncing back in the opposite direction as indicated by the path of a typical electron indicated in Figure 5.7 .

Now we introduce the average free electron velocity <v>, which is the average taken over the velocity distribution of all the electrons. The average free electron velocity <v> is identified with a drift velocity $V_d = \langle v \rangle$.

The free electrons in the conductor will all be thought of as drifting along towards the left with a drift velocity V_d. Figure 5.8. Let n be the number of free electrons per unit volume. Then in the time interval dt the amount of charge that passed the surface A is the charge dQ within the volume indicated.

$$dQ = n \times \text{volume} \times q$$
$$= n A (V_d)\, dt\, q$$

The current I that flows in the wire is defined as the rate at which charge passes through surface A in the time dt.

We have $I = dQ / dt = n A (V_d) q$

The current density is the current per unit area of cross section and will be :

$$J = I/A = q\,n\,(V_d)$$

It is important to note that since the moving charges are negative (=electrons) rather than positive in this case the direction of the electric field force (F=qE) and that of the drift velocity V_d are opposite that of the electric field E and the electric current.

Negative charge moving Right to Left increases the positive charge at the right of the section, just as positive charge moving from Left to Right does. The motion of both kinds of charge has the same effect namely to increase positive charge to the right . In both cases particles flowing out through the one end of the cylinder section are continuously replaced by similar charge (carried by the flowing particles) flowing in through the opposite end. This is a continuous process.

This situation of electron flow and net charge flow may be further reinforced by comparing it with the net flow of people through the gates at the football stadium three quarters of the way through a very dull match. The entry point (gates) is no longer being monitored and there is nobody to check who is coming in. If one is observing at the gates, most people are drifting out slowly, although a few (who could not afford to pay the entry fee initially) are still trying to get in. On the average there are more people going out than coming in for this period until the end of the match when there will be nobody in the stadium. There is a net drift of people towards the outside of the stadium. In a comparable way at any point in a conductor there is a definite drift of charge in a specific direction. In the case described above the drift of electrons is towards the left. The orientation of the electric current is towards the right.
Helm [1970] has explained an ingenious method of how to reinforce current flow and the concept of drift velocity using the Van der Graaff generator which is very useful for

those who have used the instrument.

The theory does lead to a definition of electric current in terms of n (the flowing charged particle density); q (the charge); v (the average drift velocity of the charges).

An essential component of this theory must be that electric current is evaluated at a point/cross section (see figure 5.8) as the rate of passage of charge through the surface. It is not the electric current of the whole resistor R, unless R is thought of as a point resistor.

The approach introduces quite categorically the idea of a drift velocity V_d.

The inter-atomic collision processes involved need to be explained: As the charges accelerate in the electric field, the charge carriers (particles) gain kinetic energy

$$qE\,(dS) = \frac{1}{2}\,mv^2$$

The charge carriers (which may be electrons) collide with the relatively stationary particles of the conducting medium, ions in lattice sites, losing energy at each collision, and hence their discontinuous motion. They exchange their recently acquired kinetic energy at each of the many collisions with the stationary particles of the conducting medium, and this energy is passed on to the resistor.

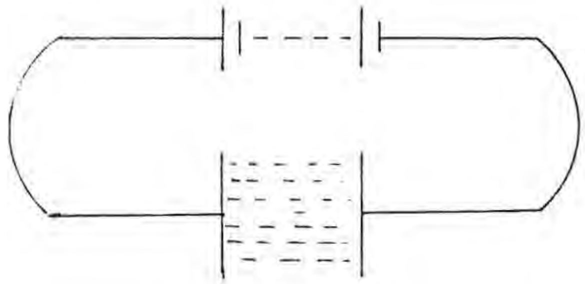
It may not be taken for granted that students in the first year at university, would not have conceptual difficulties with the concept of average drift velocity of the charges. In fact they do have such difficulty. Essentially they are unable to evaluate/imagine the average velocity especially of a particle that has discontinuous motion (the average here results because at the point where the I is evaluated each charge q crossing, has a different instantaneous velocity as explained). The velocity concept would have to be enriched. The nett shift of charge is based on the average of the instantaneous velocity of the group of electrons crossing the surface.

In my experience, many school teachers and textbooks do not make it clear that the statement:

-- electric current flows from the negative side to the positive side of the battery in the circuit outside the battery (or the other way round for conventional current)--

merely indicates orientation of flow of charge (of particle charge carrier = electron), and hence the direction only of flow of current. Most school leavers do not know that this is not an origin --> destination situation for the current; that the current does not start at a place A and then travel to point B where it ends up. Some teachers that I have met do not know this. It is worthwhile for teachers to explain that the electric current does not flow from the one electrode to the other in the sense that it ends up there (what is left of it), -- because this is a very common misconception. The above incorrect conception is reinforced partly from the misunderstanding that electricity (whatever it is; - energy, - current) is contained in the battery and flows out directly from there. It may also arise if current is represented as merely electrons which are accummulated at the negative plate and flowing out from this electrode as current to the positive electrode, to be neutralised there.

The mere suggestion that the conductor (resistor) is connected to the positive side and negative side of a battery is not enough; it must be explained clearly that the battery sets up a directed electric force field in the conductor. Some first year university general physics textbooks do describe simple experiments to illustrate the presence of an electric field between two electrodes of the battery [Ohanian 1986], and these experiments could be used to back up the idea of an electric field in a conductor connected to electrodes of a battery.



I have found, from experience, that students otherwise tend to assume the electrons are supplied by the negative side of the battery and that ultimately or at the end, their sole purpose is to neutralise the positive side of the battery.

The above mistakes lead to a few other conceptual blocks.

(i) Students find it difficult to accept that electric current actually flows through the battery or cells, and

(ii) some students make the assumption that there are normally no electrons in the conductor; that all the electrons (and hence the electric current) actually originate from the negative electrode of the battery

In the energy system approach it becomes clear that it is the charge carriers, and therefore the charge, which flow in the sense that they move from one point to another. The electric current is evaluated at the cross sectional area / point and only has a direction of flow.

The collisions also provide for the exchange of energy in an imaginable way; from the kinetic energy of the charges (charge carriers) to the energy of state of the relatively stationary ions in the conducting medium. This action would naturally lead to the assumption of higher energy states by these ions and/or the immediate ejection of the extra energy.

Students also find it difficult to assimilate the idea of internal resistance of the cell if we do not introduce the idea that current actually flows through the cells. The approach that the electric circuit is an energy system operating at steady state - when current is flowing - even through the battery, makes it easier to accept that a battery as an electric circuit component also has a resistance. The additional idea that the battery is a place where the energy is input, becomes a separate but very important conception.

In accordance with broad strategy of accommodating alternative conceptions, the field approach should also effectively stifle the unreliable (unacceptable) notion, which has been used by some teachers, that the negative side of the battery repels electrons in the conductor away from itself. This conceptual standpoint does break down as the furthest electrons would not be repelled with as much force as the ones which are near to the negative pole. Also this inappropriate conception offers no relevance for the flow of the electric current through the cell, and may lead to the "kinetic energy is lost" catastrophe.

The electric field is constant throughout a uniform conductor, so that we do not get 'tired' and slow moving electrons towards the edge of the conductor. The influence of the field is equal at all points in the conductor ($F=qE$) whether the electron is at the beginning or towards the end of the conductor.

The overemphasis on the role of electrons in current flow, detracts from the definition of electric current, I=dQ/dt, as the rate of flow of charge. It should be discouraged. Electric current is a rate of flow of charge evaluated at a cross section, and not "in" a resistor as if it is residing there. Students tend to focus on electrons (particles) as carriers of electricity (=energy? or =current?), not necessarily charge, and refer to flowing electrons as flowing current. As a result it is more difficult for them to accommodate the so called conventional notation that requires positive charge (current) to flow from the positive side (higher potential) to negative side (low potential) -direction only-. We should take account of this. One has to admit that this idealisation is at a higher level conceptually and has no concrete level associations. Although traditionally the latter is introduced later in school, it does not stick as the interviews have shown. Students would rather think concretely in terms of electrons (particles) and as a result a sizeable number are even prepared to consider the newly defined current as the movement of protons.

I have the impression that the theory of battery function, electrolysis theory etc; as it is taught / found in the average school textbook, affects adversely the direct current concept formed in students. It emphasises almost singularly the build up of electrons and charge at the negative electrode. It does not make it easy to accept that, when the potential difference is maintained across the battery, charge does in fact flow inside the cell between the electrodes [and hence current] against the field direction indicated.

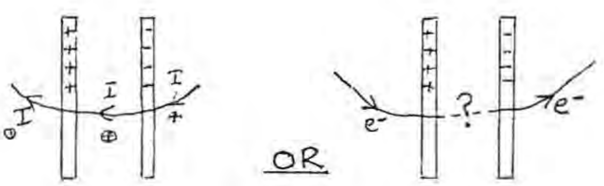


Figure 5.9

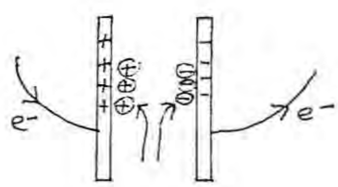


Figure 5.10

The seeming cross flow of positive charge to anode and negative charge towards cathode during electrolysis confuses this last point. Normally in their conceptual frame the drift of + and - charge in opposite direction inside the cell (Figure 5.10) indicates to students no net shift of charge in any one direction and therefore no current flowing inside the battery.

The teacher has to attempt to resolve the issue of charge flow in the battery since it is not acceptable that electrons will actually flow from the positive electrode to the negative one inside the battery, even during current conduction. The process in the battery does not involve actual electron transfer as suggested by the representation in Figure 5.9 above.

The emphasis here is that we are dealing with charge flow (hence current) and not with electron flow.

We have explained earlier that a (+) charge moving to the Left ← (+)
is equivalent to a (-) charge moving towards the Right (-) →

Then the representation in Figure 5.10 above is equivalent to :

Figure 5.11

No electrons actually flow inside the battery between the electrodes; positive charge does. In this treatment we have not been concerned with the flow of charged particles as such but with the flow of charge carried by these particles.

As a teaching strategy it is useful to avoid emphasis a need at an electrode because of shortage of electrons for example at the anode, and/or extra electrons there at the cathode. This conceptual framework indirectly implies that in the outside circuit the electrons migrate to anode (positive) to neutralise it or fill in the gap there. This approach is not on. One reason for this is that later on, and as a result of it, students have a difficulty in understanding that a point which is at negative potential with respect to an initial point may actually be at positive potential with respect to a third point along a line; hence there is a difficulty in establishing why current flows between the second and third points. Incorrectly it sets out the purpose of flow of electrons (and hence of current) in a circuit as being to neutralise the positive electrode in the circuit.

The appeal of the electric field model (energy-system approach) is that one does not have to emphasise the specific mechanism of energy input into the circuit at the source (cell), or how the field is set up. Thus examples of other types of generators of the electric field, or emf would be covered by the same explanations. As a broad approach it, in fact, covers other circumstances as well. It covers the action of the photo-electric cell, which may also be used to reinforce the idea that there is continuous energy input into the electric circuit at the source (battery). The bicycle light generator is also a useful example.

The d c current circuit is an energy system. It is not really an electric current system. It should be taught basically at school through hands on activities, along the lines indicated in the paragraph on potential energy difference, to reinforce the discernable behaviour patterns. An entirely theoretical approach is bound to fail. Unfortunately the latter approach is used in the majority of black schools, largely because of the shortage of not only laboratory facilities but also of experienced and qualified teachers.

In dealing with most inappropriate conceptions of current the instructor has to be constantly mindful that most students have basically inherited from their background the fluid metaphor intuition of current [Johsua and Dupin 1984]; namely, a model of a flowing current which is at once a fluid of matter and a fluid of energy. The problem of the student [as he sees it] is how to explain that the [material] fluid conserves itself and, at the same time, as energy [the fluid] *exhausts* itself on passing through a resistor as evidenced by the light, heat coming off the bulb and by the wearing down of the battery in time.

5.4.2 Electric circuit as an Energy System:

Concepts of Energy:

Normally by the end of school in standard 10 and at first year university the students should be able to recognise the simple electric circuit as an energy system. Hence they should be able to manipulate conceptually potential -energy- difference which is used quite extensively in the basic theory, doing rounds as p.d., voltage etc;.

Since the charge flows in one direction in a closed field eg; a closed electric circuit, this would imply that there must be a region (or regions) in the closed circuit in which the d c charge flow direction must be opposite to the electric force acting on it.

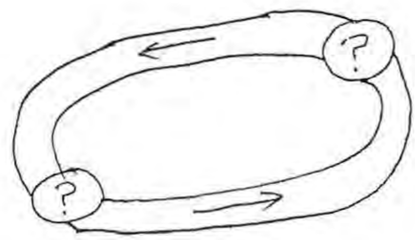


Figure 5.12

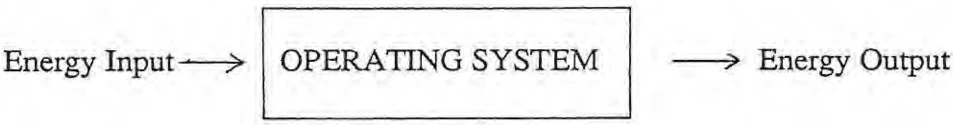
In the regions inside the resistors (conductors), charge flows in the direction of the electric field force, and energy is transferred to the charges; and later on to the large relatively stationary ions / lattice site occupants of the conducting medium. In the region where the charge flow opposes the electric field force direction, energy is added to the field [Roberts 1983] (work done to maintain the electric field = energy given to the electric field). This last region is clearly the site of the electromotive force, since this seat would be the source of energy of the circuit, by definition. There should be no more attention given to this source except to emphasise that charge does flow through it (in the *wrong* direction), and that since it (the cell) has a physical structure it will also have an internal resistance.

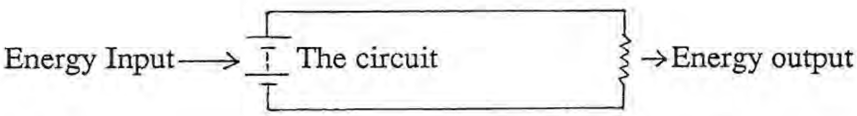
This approach emphasises the prerequisite that charge (and hence current) does flow through the cell as well, and also that energy is supplied from within the cell (battery), as a result of extraneous happenings there. It sorts out the energy transfers in the circuit more logically and sequentially. In starting with this electric field based theory, the assumption is that the students have a basic physics background and will have been introduced to gravity and the gravity field earlier on. I do not think this is unreasonable as action of the gravity field is dealt with in standard 9 in the South African schools syllabus. Discussion of the electric field could actually enhance the field concept in the minds of the students. In the approach that I propose, the electric field concept would be dealt with to some extent.

It is useful to emphasise that the electrical system is an energy exchanger only when it is operating ie. only when current is flowing. The cell (battery) as such is an essential part of the system, the agent of inputing energy into the electric circuit system (from outside it), as the system is operating. As a physical part of the system it will have to be depicted as having an internal resistance since the current flows through it as well.

The closed electric circuit: An operating system:

As an energy exchanger





at Battery
thro' chemical
processes in
maintaining Electric Field
in the conductor

at resistors
(as heat, light etc)

The electric circuit is a paradigm of an energy system and can be explained in terms of energy exchanges satisfactorily without getting into details of the mechanisms of energy input into the seat of electromotive force, be it a chemical cell or other. In the conceptual model which we have used it is clear that the electric field set up in the conductor gives energy (kinetic) to the charge carriers (particles):

$$(qE) \times dS = \frac{1}{2} m v^2 \text{ (of the charged particles carriers)}$$

which in turn exchange the energy with the relatively stationary particles of the conducting medium (or lattice site ions in metals) during a collision. Since the electric system in which the charges (particles) move is a closed path, the charges will move through the battery against the electric field and, in this region energy is supplied to the field.

Thus in the conductor the electric field supplies energy to the charges (charge carrier particles), and from inside the battery (source of emf) the energy is supplied to maintain electric field. I think that at this level it is sufficient to introduce this system in this way. There is no need to go into the forms in which the energy is supplied (or input in cell), against the flow of the field (inside the cell), to separate the charges and hence maintain / set up the electric field which is the prerequirement for the flow of current in the outside circuit.

Energy Input = Work done to maintain the field
(per unit time) (per unit time)

One might suggest that this is done through chemical processes in the chemical cell. The battery maintains the field in the conductor through maintaining the charge separation.

It needs to be emphasised that any single charge carrier, in its journey through the conductor, would have very many collisions, losing energy each time, but that as long as they are in the constant electric field in the conductor the carriers keep on reaccelerating (getting energy from the field), and colliding afterwards with the relatively stationary particles of the conducting medium and thus losing this energy to the relatively stationary particles of the conducting medium or lattice site occupants in a metal conductor. The energy acquired by the conductor (by lattice site ions), is given off as heat, light etc, so that the conductor may maintain its initial energy state.

The idea of electric potential energy difference across the ends of the conductor is relatively abstract and should only be introduced later. Hopefully at that stage the learner would be able to assimilate it. It is very important to make it clear that energy is not used. Contrary to secular and life world beliefs / meaning, the energy merely transforms / is exchanged between any two entities. From this theory it should be clear that inside a given conductor, the average kinetic energy of the charge carriers is the same everywhere. The average velocity of a typical charge carrier just before leaving the resistor would be the same as just after entering it. The steady state is the operating state of the whole action.

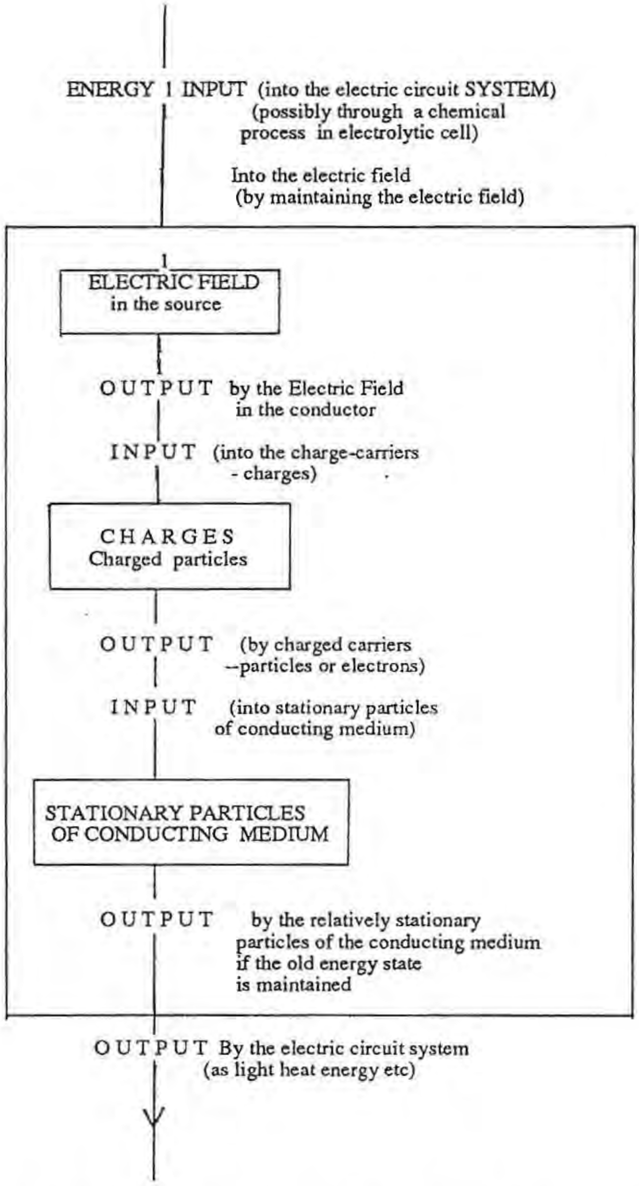
The negative charge carriers (=electrons) do not all originate in the cell but some are in the conducting material when the circuit is closed. This is true in spite of the fact that the battery has an apparent excess of negative charge on the -ve electrode. By the same token charges (and carriers) are not lost in the conductor. The electric field proposition also solves the puzzle of where the electrons which are already in the conductor get the energy from, in order to start moving on, since they are not in the battery. It encourages students to throw away the incorrect conception that electric current originates from the battery as charge which has accumulated there at the electrodes.

Thus in the system what we are concerned with is energy transfer.

Energy (not necessarily defined in any observable form):

(i) is INPUT into electric field in the source (of emf) and
(ii) OUTPUT by the electric field in the conductor;
(iii) INPUT in charge carriers (charges) by electric field
(iv) and OUTPUT by the charge carriers into the "stationary" particles of the conductor during a collision.

(v) Output as heat, light etc; by the stationary particles of the conductor if these maintain their own original energy status.



In this way it should become clear that the source of all the energy is outside the system and that in the end the energy is output by the system (to outside it) possibly as light energy or as heat energy.

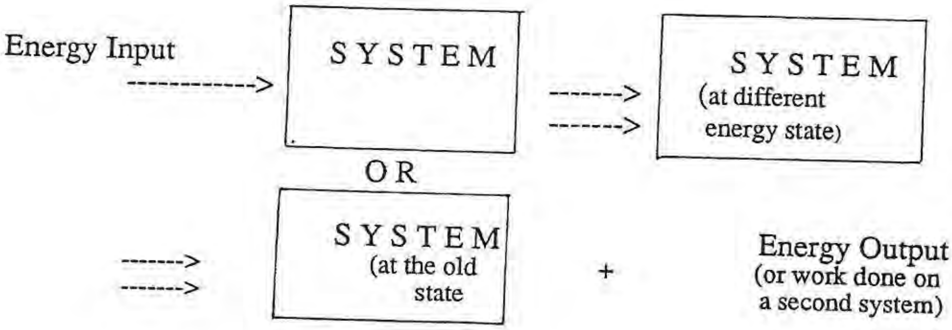
The electric circuit as a system may possibly be conceived as a converter of one form of energy (INPUT --chemical ?) into another form of energy (OUTPUT --light energy and heat energy as in lamps etc;). There is no energy consumed by the electric circuit, neither is there charge which is used up. These two (energy and charge) are normally subject to laws of conservation, in any case, according to the principles of physics. No electric current has been used. In fact no energy has been used. Thus at best, during the steady state flow of electric current a form of energy (Input) has been converted to another form of energy (Output).

Energy input ⟶ [SYSTEM] ⟶ Energy output
(=chemical?) (= light eg bulbs)

In students minds there is some confusion, inherited from other areas of physics, notably mechanics but also from life world situations, with regard to the relationship between work and energy.

In explaining energy flow to students as illustrated above, it is important to adopt a clarification along the lines indicated below. This could also be done in connection with the exchange of energy by the particles in the lattice positions in the conducting material.:-

ENERGY INPUT into a system (=the activity of work on a system) may result only in change of energy state of the system or immediate OUTPUT (of an equal amount) of energy by the system on which the work was done (or energy put in); OR a Combination of these.



It is misleading to think (as some students do) in terms of work done by one system and energy gained by a second system; rather wise to think in terms of work done -on- a second system and gain of energy by that very second system. The Work-Energy principle relates to a single system.

This does not imply that we should forget the work doing agent but for this purpose it is part of another system.

Energy considerations need to be emphasised in the theory; the battery as the 'supplier' of energy and the other components as the converters of energy to other forms perhaps eg. light heat energy etc. The electric circuit system should be taught as a dynamic system (operating at a steady state) in which the battery continuously inputs energy by maintaining its electromotive force and the electric field in the conductor; -- through the energy supplied (input) by the chemical processes, in the chemical cell for example.

As in other conceptual schemes (in physics) energy is central in the theory and time should be spent in explaining energy not only in terms of fast moving objects (kinetic) but also the concept of potential energy. Potential energy [hence potential (energy) difference = p.d] is not a physical form of energy in any real (mechanistic) sense. Otherwise students grapple, without success, with how electrical potential energy may be transformed physically in the resistor to heat or light energy. If the energy concept is not explained, life world notions of it take over with disastrous consequences. For example, I have diagnosed that light and heat are perceived by students as merely sensations really. Energy as a concept is much larger than the physically realisable/observable forms of it (e g light, heat), and my thoughts on this are that as a broad concept it should be freed of these physically perceptible associations. Energy results in the change of or is symptomatic of the state of a system.

Meanings and reasons for energy conversion have perpetually bothered students and hindered conceptual development. Students worry continually about the mode of energy transfer (in a mechanistic flow sense) from one point in a circuit (cell) to another point (lamp, say), and seem to be confused when a non observable potential energy form is converted to a form which is observable like heat, light etc. There have been commendable efforts to address these problems by some researchers [Duit 1984; Warren 1982].

5.4.3 Concepts of Electromotive force and Potential [energy] difference:

The research has shown that potential (energy) difference as a concept is not well understood by students [75%) in my case], although it may be in circulation as voltage when students think about electric circuits. The incorrect conceptions take various forms, some of which have been articulated in the earlier chapter. The study by Duit [1984], has also indicated several limitations in basic aspects of the energy concept. The student tends to attribute an observable energy form to the potential energy of charged particles, the amount of which is supposed to diminish along the circuit because it is exchanged out / or consumed etc by the circuit component. Potential (energy) difference (=p.d) is the most frequently used concept in the theory alongside current; it is probably the least understood.

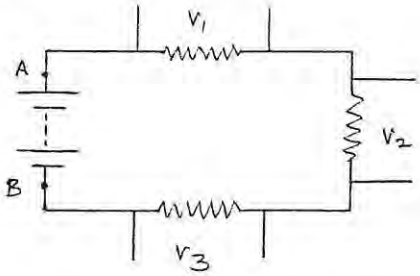
The concept of "potential" energy is in itself quite difficult and should rather be left alone at this stage. There is a relativeness about the concept. In my experience as a teacher for twenty years, I have found that most teachers that I have come into contact with do not understand the concept of electrical potential energy. A large number of students seem to think in terms of the energy as being actually possessed by an electron, in some way that can being observed. A recommendable approach to the teaching of potential difference is through the use of experiments and measurements. In using laboratory activity one should try to distinguish between the electromotive force (the energy input aspect) and the potential (energy) difference across the other components in the circuit (normally the energy output aspect of it).

The electromotive force should be taken as a "given" in this situation and not something to be determined by connecting a voltmeter across the battery. It represents the energy per unit charge input into the battery; the energy output by the battery to maintain the electric field in the resistors in a closed circuit. Normally batteries are standardised and manufactured to have certain emf's. The emf of a battery does not depend on what the other components in a closed circuit are. The essential nature of the emf is that it a measure of energy input into the electrical circuit.

It should be pointed out that experimental methods for the determination of the emf are available, albeit relatively more sophisticated, eg using potentiometer etc; the main point being that the electromotive force can only be measured when there is no current flow through it.

Given the value of the electromotive force initially students may be made to determine in a closed circuit, using a voltmeter, the potential energy differences (=p.d's) across each of the other circuit components (=resistors).

Illustration:



Determinations using standard laboratory equipment are satisfactory in this scenario. Measurements will show that:

V ab = V1 + V2 + V3

If the battery has negligible internal resistance these results should be able to show that:

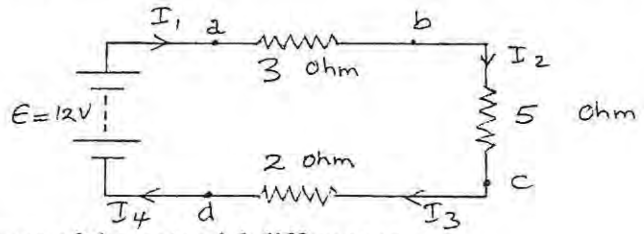
E(emf) = V1 + V2 + V3

The aim would be to establish that:

the emf, E, is equal to the sum of the potential (energy) differences.

The energy input into the circuit is equal to the energy output out of the circuit in a time interval.

Using the example below the illustration could be as follows:



E (given) = sum of the potential differences
E (input) = sum of the energies output
as determined using a voltmeter
(care should be taken to avoid using the word "voltage" at any time during this exercise)

E = V1 + V2 + V3
(The current, I, could actually be measured through the insertion of an ammeter at each point)

I1 = I2 = I3 = I4 = I etc; in the series circuit
E = IR1+ IR2 + IR3
12 = (1,2)3 + (1,2)5 + (1,2)2

12 volts (input) = [3,6 + 6 + 2,4] = 12 volts (output)

12 joules per coulomb = 12 joules per coulomb
(Input into d c circuit system at battery) (Output by the d c circuit system at resistors)

If the current flowing in the circuits [1,2 amperes] = 1,2 Coulombs per sec; then

Total Energy output by all resistors :-
1,2 coulombs per sec x energy output by one coulomb thro' declared p d
= 1,2 C/s x 12 J/ C = 14,4 Joules per sec

Eg. Energy output by the 5 ohm resistor
= p d (=energy by 1 C) x 1,2 C per sec
= 6 x 1,2 = 7,2 Joules per second

This is not always obvious to first year students.

The exercise could be tried out with several other combinations of resistors initially in series combinations, including three or so lamps on a standard so called Worcester circuit board. It does work.

There is a simple experiment which could be done to reinforce the idea that energy (=heat) in volts unit current is given off at the resistor (heating coil). This experiment is illustrated below, and is indicated in the standard 10 syllabus.

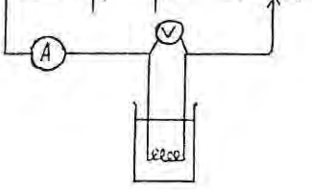


Figure 5.15

[HEAT] Energy given off by coil = Volts x ampere

= Joules/ coulomb x Coulombs /sec

= Joules per sec

This energy is measured in terms of the rise in the temperature of the water.

Earlier on the role of concept names was emphasised:

In order to reduce conceptual noise from words to which we cannot by primitive instinct attach meaning, for example volts, amperes etc, teachers should try to reduce terms to basic descriptions.

Amperes = charge in coulombs per sec (at a point)

Volts = energy (joules) per unit charge

(given to the electrical system at the battery, if it is emf which is being evaluated)

(taken out / exchanged out of the electrical system at the resistor (lamp), if it is p.d which is being measured

Expression in the more fundamental units will make the student realise that, in electric circuit theory we are dealing with

(i) amounts of charge flowing through (or passing) a point (=current);

and

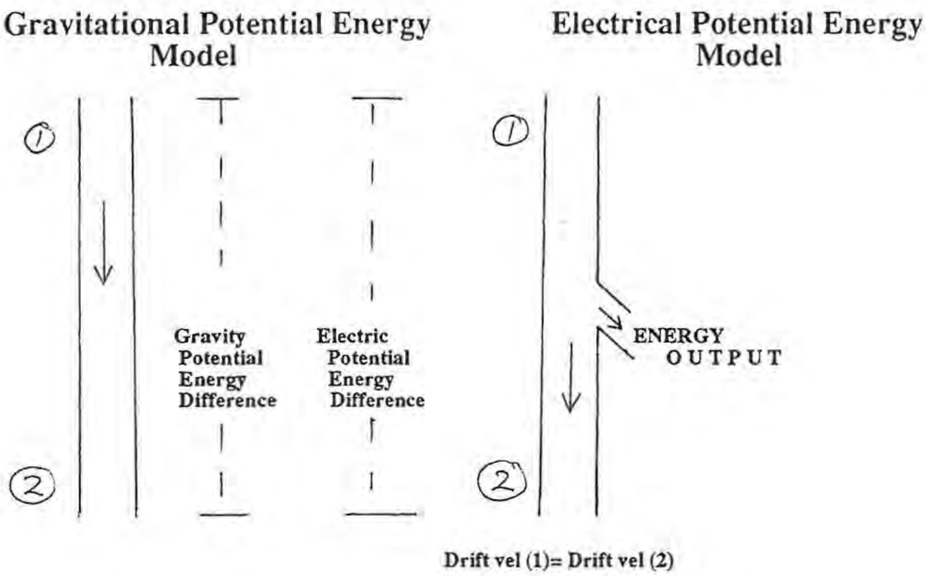
(ii) amounts of energy coming into and going out (=volts) of electric circuit system.

A 12 volts (emf) battery is a 12 joules per coulomb (unit charge) battery. When the system is operating, the battery inputs 12 joules per unit charge into the electrical system --and not into a specific charge. The expression of .."per unit charge" . simply denotes a measure of the amount of energy input. This energy is not immediately passed on to a single charge in the battery which will from then onwards possess it. What this implies is that a unit charge has the potential ability to cause 12 joules (energy) to be released out of the electric circuit system at the resistors/lamps as the hypothetical charge flows round the circuit back through where it had been noted originally. A particular charge does not have to begin its journey at the battery; it can begin its journey anywhere in the circuit. The instantaneous value of the average kinetic energy a charge carriers is the same throughout the motion in the circuit; it is worked out from the "drift velocity".

An effort should be made to satisfy students that the force experienced by a charged particle with unit charge q^+ ($F = q^+E$) in the electric field in the resistor is on the average equal everywhere inside the resistor. This should have the effect of counteracting the unacceptable conception that the average kinetic energy of the flowing electrons is reduced in movement through a resistor. The students would argue, incorrectly, that if the force becomes less along the resistor then this "fact" justifies the conclusion that the flowing electrons would be slower after the resistor, and hence the current as well.

As a fundamental strategy it was important that I should address the thinking frameworks of the students --their inappropriate conceptions - as I had determined them. . Below is an example:

The differences between the gravity potential model (of a freely falling object) and the electric potential energy model (of a charged particle moving through an electric field in a resistor) should be pointed out. The main reason why this should be done is that students inadvertently use this model for conduction of electrons in a resistor.



Average K.E at 2 > K.E at (1)

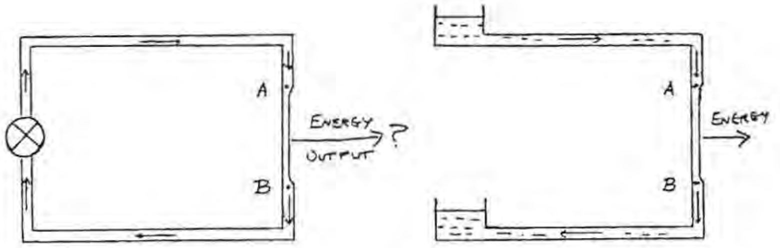
Gain in the kinetic energy
of the falling
(in gravity field)
particle

Average K.E at (1) = K.E at (2)

No change in the kinetic energy
of the falling
(in the electric field)
particle

Besides the drift velocity concept is a different concept altogether and is not the velocity of any one identifiable electron as such.

When the electro-pump and gravity models of current flow are used [Duit and Jung 1984] to model the concepts of electric current flow and potential difference, it is not always stated clearly that in the electric field energy situation, energy is output as the falling (flowing) object moves through the electric field, unlike in the gravity case. Thus the water model is misleading about potential energy difference in this respect.



The water pump / electro-pump model may illustrate the instantaneous flow of water / current very well but

(i) students are not really familiar with water pressure differences.

(ii) It is not clear if energy is output between the two points A and B between which there is a water pressure difference.

The gravity-pump system, unlike the electric system, often does not constitute a closed system anyway.

5.4.4 Electrical resistance :

There is a problem with the word resistance. It should be explained to students that a resistor does not oppose electric current or slow it down as the current passes through it. This last idea may actually have led to the sequential model of current inappropriate conception of Riley [1981], Shipstone [1984] and others.

Otherwise the concept of electrical resistance is normally new to the student - it is not from his life world. Although its conceptual meaning might be biased by the common language meaning of the word, strictly speaking its physical meaning and conceptual understanding will depend on how it is taught.

The value of R for a particular conducting object [resistor] depends on the material of which it is made, and on the geometry of its construction. For a very large class of materials it has been found that R does not depend on the potential difference V across its ends. For a particular conductor the value of R is fairly constant, and although it may be expressed as $R=V/I$ it does not depend on any single value of V or I independently of the value of the other one. With this class of resistors there is a linear dependence between V, the potential difference across the resistor, and I, the current through it such that R always has the same value. In other words when V increases for some reason the value of I will also increase proportionately and vice versa. These resistors are the most common and are said to obey Ohm's Law.

There is a less general class of resistors where the value of R has been found to depend on the p d across the resistor especially for extremely high values of V; and some where R depends on temperature eg; diodes, semiconductors, transistors etc . Indeed with any extremely high voltage any material can be made to deviate from Ohm's Law.

It would seem that an effective and viable method of introducing electrical resistance and its quantitative value is to use an actual experimental approach [Arons 1978; Evans 1979], and to discuss results supposedly obtained from experimentation and leading to $V = I R$ or $R = V/I$ across a resistor in an electric circuit. As this approach is used at the schools level, it is a worthwhile starting point at tertiary level.

Ideally at schools' level it is best to reinforce the resistance concept from the point of view of an analysis of the atomic processes involved in electrical conduction. This model is attractive especially because it relates to the energy exchanges in the electrical circuit. One hesitates to be prescriptive here. It should be mentioned that the resistance of a conductor is evaluated normally at constant temperature; although in its more complex form it may be temperature dependent. The concept as quantified is relatively complicated and various books use different approaches, but in the end attempt to unify the concept; Iona [1979], illustrates this conflict well.

The introduction of obstacles to flowing particle charge carriers, in the nature of the relatively fixed or stationary particles /ions of the conducting medium, and the collisions of these with the flowing charges (electrons) does introduce subtly the concept of electrical resistance. The collisions also provide for the exchange of energy in a more imaginable sense, from the kinetic energy of the charged particles accelerated in the field to the energy of state of the stationary ions within the resistor. This would lead naturally to assumption of a higher energy state at the resistor and/or the ejection of this energy immediately afterwards as light energy, heat etc.

In the water flow system analogy, the dependence of electrical resistance on length and cross sectional area of the wire ($r=\rho l/A$) is also reinforced at least qualitatively by the resistance of a pipe to the flow of fluid. In the model a source of electromotive force is considered to act like a pump, and potential differences are compared to fluid pressure differences. Current (or charge) passing through per unit time is usually modelled as fluid volume passing per unit time. In an incompressible fluid (the model) the flow starts almost immediately through out the whole system as the valve is opened, if the pipes are already full of fluid. This last point illustrates with success the electrical case where, although the drift velocity is small (about 1mm per sec in copper), the electric current flows throughout the circuit almost instantaneously on the closing of the switch.

However one has to be careful and guard against the misuse of an analogy. It does not represent the whole story, and one should not expect to derive answers that the model cannot give. At close scrutiny of the two systems, in fact the dependence of "resistance" on the cross section of a wire (pipe) is different for the electrical case, from that of fluid flow inside a pipe. The intrinsic existance of resistance is essential for the emission of energy (eg. light and heat) in the intermediate stage in the electrical model. This output of energy is not obvious in the water flow model. Hence potential (energy) differences cannot be successfully taught using this model.

Also in my experience, and in so far as the pressure difference is concerned, the effectiveness of this model is in doubt, as students even at school leaving age have no critical appreciation of fluid flow, pressure and especially pressure differences. Higher pressure suggests a bigger force acting on the electrons here as compared to the other point.

At the University level it is unavoidable that the resistance concept should be enriched also through a quantitative analysis. Below is indicated an approach that may be used:

The electric current as defined at a point may be expressed as follows

$$I = A \sum nq\,(Vd)$$

as explained in an earlier paragraph;
and the current per unit cross sectional area as

$$J = I/A = \sum nqv$$

The current density, which is proportional to J, may also be expressed as

$$E = \rho J \qquad (\text{OR } J = \sigma E)$$

where ρ is the resistivity and σ is the conductivity.

The assumption of course is that the students have some background in physics, especially in the practical measurement of electric current and potential difference, as discussed earlier in the section on energy.

The above equation is particularly relevant because it deals with the properties of the conducting material at a cross sectional area (point), rather than of the device / resistor as a whole. It should reinforce the idea that electric current is evaluated strictly at a cross section and not for the whole resistor.

It should not be difficult to lead the students from the equations above to the more familiar (and popular) expression for electrical resistance.

$$E = \rho J$$

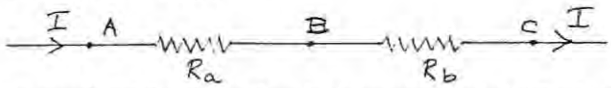
$$\frac{V}{d} = \rho \frac{I}{A} \quad \text{where} \quad E = V/d \text{ and } J = I/A$$

$$V = \left[\frac{(\rho d)}{A} \right] I = R\, I$$

and thus $R = \dfrac{p\, d}{A}$

An additional point to reinforce is that, according to the electrical energy model, the battery sets up a field in any conductor across it, and hence would normally "cause" some current in an additional (parallel) conductor independently of whatever other conductor is connected in parallel with the first one. The battery is *limitless* in this sense (risky to say) in that even other parallel resistors would "draw" current independently of what else is connected, for as long as each of these is connected directly to the source. In this way one assumes there will be no problem in the students' mind with the battery seemingly being able to "produce" more current than at first, when there was only one resistor in the circuit; that is, with the extra resistor in parallel making it possible to "draw" additional current from the battery. A warning must be given here that in the ordinary torch batteries and bulbs experimental set up, two bulbs in parallel often do not "draw" twice as much current from the torch battery, because of the battery's other physical limitations. Consequently torch cells should not be used in any experiment if the point is to show that two lamps in parallel 'draw' twice the current.

In the spirit of trying to correct for inappropriate conceptions where they seem to occur, it is important to emphasise the broad principles of Kirchhoff's current rule. Through a single resistor, the amount of charge that goes in at a given time is equal to the amount that comes out at the other end. If there are two or more resistors connected in series, equal value of current is indicated at all points along each of the resistors, irrespective of whether the two are of equal ohmic value or not. The rate of passage of charge (=current) is the same for both, otherwise there would be an accumulation of charge at the point between them and the condition of continuity of current in d c circuits would not be satisfied; this is not allowed by the theory.



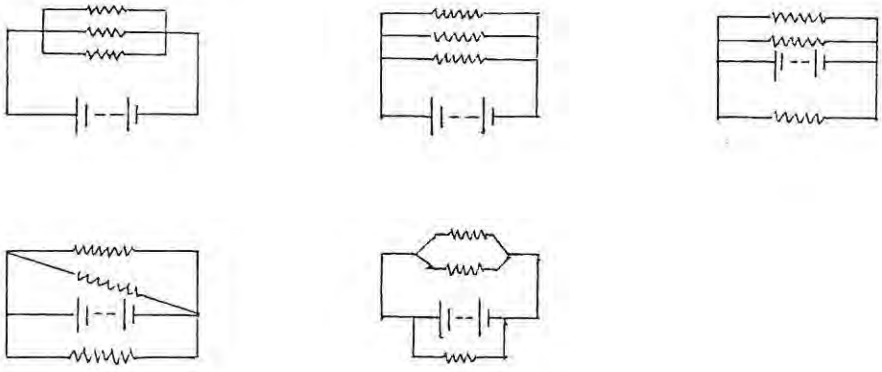
The current through R_b is not determined independently irrespective of Ra but from the collective value of both resistors. The potential difference across R_a is IR_a and that across R_b is IR_b, where the current I is of the same value for both R's. The potential difference across R_a may thus be smaller than that across R_b if R_b is larger. This definitely does not mean that the electrical potential at A is smaller than that at B. There will still be a potential energy difference (=p.d) between A and C. Thus current will still flow in the direction from A to C.

5.4.5 Circuit diagrams, symbols and representation in general :

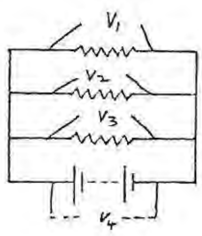
Circuit diagrams and symbols feature prominently in the misconceptions that students have in simple circuit theory. In the interviews at least 40% of students were disturbed by the discontinuity in the circuit suggested by the symbol for a cell. Earlier books had used the symbol {—||—} in place of {—| |—}. The impression I have is that the problem here lies with the development level at which students think and interpret mathematical, graphic and other representations.

The connecting wires in simple circuits, (supposedly with zero resistance) and connecting lines in diagrams imply that current flows in these parts to reach the resistance only later. This creates problems in the student's mind as 'nothing' happens in between although current flows in these lines. This encourages the idea that energy (or even current and 'voltage') is transported (without incidence and/or mishap) from the battery to the lamp (or whatever other component) where it turns into light; the origin - destination syndrome. Also since current moves in the lines there must then be a p.d or voltage in the line.

As a rule, most students will have problems in recognising the similarities in the following diagrams:



and will read different values for the potential difference in the following situations.



These problems could be made less if circuit diagrams were standardised or if certain standard ways of doing these were preferred. The students could also be given practice in the representation of electric ciruits in terms of diagrams. Fortunately laboratory experience in the connecting of circuits, and practice in representing these, will eliminate most of the problems and help familiarise the student with circuit diagrams.

More time could be spent by teachers to emphasise that the physics theories, and the representations which are used, are in themselves merely models and symbols used in exemplifying the behaviour of natural phenomena. At best these models only approximate natural behaviour in the way we present it. Natural behaviour, hopefully, does not change but it is our perception, subsequent modelling and representation of it, that may improve with time.

5.4.6 Words and their Conceptual Meanings:
The Role of Language:

The last item on teaching strategies involves reducing conceptual noise levels by, for example, choosing and using words judiciously and appropriately when teaching. Here one has to bear in mind that scientific language is formal, as opposed to the non-formal colloquial language of ordinary conversation or communication in life world situations. Formal scientific language may use words with unfamiliar meanings and usually has a relatively high concept density. By contrast, in non-formal language the concept density is low. Informal language has a level of precision which is generally low and variable unlike scientific language which has a high level of precision. It is not uncommon that when one is criticising students' work one has to argue perennially that it is not just the final answer [the words] that matters, but the method of arriving at this correct answer which is most crucial.

My impression is that the above considerations are particularly pertinent when teaching students whose home language is not that in which they learn. For the black students the English language, through which they learn science, has to be learnt under formal circumstances, and is not normally spoken outside the classroom situation. There are bound to be problems with metaphor in the language.

Learning science is almost like learning a new language altogether. For physics to be understood it requires unambiguous language and, for its message to bear fruit it must refer to events which are within the experience of the individual physicist, and which are reproducible. Whilst one must concede that the physicist's picture of reality is in terms of models and metaphors generally drawn from a/the more familiar field of knowledge, there is no doubt that words like work, energy and current for example, need to be defined more comprehensively in a physics sense, before being used as part of scientific jargon. The English language seems to imply notions on electricity, namely in the way we speak about electricity and electricity devices in daily life, which are not correct in terms of physics. In everyday life we do *use* electricity and do *charge* batteries so that we can get more *'electricity'* out of them.

We need to explain for example that electromotive force is not a force, both in the common sense meaning and in the mechanics meaning of the word; that energy is not used in the physics sense. We need to teach students how to discriminate between life-world and scientific meanings [Solomon 1984] In this way we would hope to put the effects of the pre-emptive life world conceptual schemes into proper perspective. We could not hope to get rid of them altogether. Words for concepts will always be used in a non-scientific sense in common language. The precise theories of science and its formal definitions have to be connected, as realistically as we may, to the life-world knowledge of our students and interpreted in the light of all "knowledge" which has superseded them in students' minds.

It is incorrect to accept that words like work, force, and energy merely adopt additional conceptual dimensions. "Work" in the common sense meaning is associated with personal exertion, and work done by an agent. Work done <u>on</u>, as determined and measured by change of energy state or other effect, is more appropriate in scientific language. It is misleading to use examples of man "using" energy to run as a result of which kinetic energy is gained, when one is exhausted (from lack of energy) during this process. If we do we should not be suprised when students talk of electrons (current) which are tired at the end of the circuit, presumably because they have lost energy.

Also, we are using incorrect language when we say "current goes round the circuit", "passes the resistor and then divides into two parts where the resistors are in parallel", "before it enters the battery" . If we did say these things in our explanations then we are encouraging students to think that current actually moves from one point to another and to think sequentially about it.

The structure of language may lead or mislead the thinking process. The logical structure of the English language leads to a way of thinking which is not appropriate to electricity. This appears to be especially true for the inabililty of students to think of the electricity circuit as a system. Language seems to be organised in simple sentences, with subject, verb and object: subject causes this / has this effect on object. etc, especially to those who are not conventionally English speakers. The tendency is to think in single cause-event elements. This has an important impact on the learning of electricity, where students tend to concentrate on local processes, and prefer to reason in sequence when dealing with problems of the electric circuit. Examples of this are apparent in the indiscriminate application of E=IR for each resistor, especially in problem solving. In the interviews some students were unable to give the value for p d across one of two equivalent lamps in series because they did not know the value of I and R for the lamp. This was in spite of knowing the emf of the source. This is perhaps another example of thinking sequentially about current. The students could only think about one resistor at a time etc. They seemed to have difficulties with taking into consideration all parts of the circuits the same time.

On the use of analogies, surely one can understand that students expect current to be higher (faster) in the thinner part of a constricted wire than in the thicker part, because electrons have to move faster through the thin part. The indigenous language of the student has a considerable influence on his scientific knowledge; as part of his culture it provides notions. In grappling with an idea he may, without even realising it himself, fall back on his mother tongue. For example the equivalent word for current in Xhosa is "umsinga". Unfortunately in this latter word there is an emphasis only on the speed at which things rush through a point, as it is often used in the context of flowing water. The student may easily understand that the current will be fast (=large) when the conductor appears to become thinner. As a result he may get the idea that with an electric current it is the speed of the electrons only that matters. He will then conclude that the current is higher at a point where the conductor is thinner. In other situations students may not be able to fall back on to any meaningful equivalent word in their mother tongue, and this can also be a disadvantage.

We have already suggested that the word *voltage* should be habitually avoided, and that potential energy difference and possibly electromotance [Sears et al 1986] be used. A high voltage at one point and a lower voltage at another point along the same line inadvertently leads students into thinking of the *voltage*, whatever it is, as being consumed (at least disappearing) in between. The word *voltage* tends to lead to confusion between the energy supplying (emf) and the energy output (p.d) aspects of the circuit. In this particular study there were too many students describing potential (energy) as the *potential* ability of a battery to supply some volts (or some voltage) to the circuit.

Flow of current from negative to positive is merely an indication of the direction and not the actual movement of the entity 'current' from one point to another. Electrical resistors are not there in a circuit to "resist" the flow of current, or to slow it down sequentially, as current is determined at a point anyway. Current is not going to be slower or less on the other side of a resistor. Current is not supplied by the cell even as charges, the battery only maintains a potential difference across the lamp. I have mentioned earlier that it is preferable to the use of more basic 'words for concepts' initially; it is better to speak of coulombs (charge) per second than of amperes, of joules per second of energy output as light instead of just light energy given off, and so on.

It is clear that the interpretations of words and scientific phrases will greatly affect the conceptual learning of students, especially those who have disadvantaged socio-cultural and learning backgrounds. Some words do have scientific meanings according to which the associated concepts link and interact with other concepts, and become assimilated.

5.5 Conclusions:

My own experience, and that of other teachers / researchers, indicates that traditional teaching strategies are not an effective safeguard against the acquisition of / construction of inappropriate ideas about current electricity.

This problem arises because the students are subject to a variety of influences, such as

i) personal observations of natural phenomena interpreted in the light of previous experience and / or socio-cultural background;

ii) meanings commonly attached to key words in the students' own language;

iii) misleadingly worded statements in textbooks students read and from teachers who actually present the subject matter formally to them;

iv) misleading images presented by public media, newspapers and television etc on topics which students regard as essentially topics of a *scientific* nature.

As possible ways of countering these influences, I have proposed some specific strategies, which I have found useful and used in my special situation and experience.

These proposals rely on the adaptation and modification of existing traditional methods of presenting the subject matter. As an example here I may mention the emphasis on treating the electricity circuit as an energy system in which energy is conserved, and not a current system.

In the chapter to follow I will be looking at ways in which presently held and identified inappropriate conceptions may be accommodated. The incorrect conceptions will basically be attended to using conceptual change strategies and cognitive conflict.
Examples

:i) Interviews, interviews in a practical situation

ii) conceptual development using the scheduling of class experiments.

CHAPTER SIX

RE-INFORCEMENT OF MORE APPROPRIATE CONCEPTIONS USING AN EXPERIMENTAL SETTING:

In this section I indicate how specific inappropriate conceptions of students can be used as departure points for more elaborate knowledge construction.

6.1. Use of clinical Interviews:

High school graduates will always have problems with phenomenological reasoning, partly because of their so called intellectual maturity level but more significantly because of the teaching approach used in the school textbooks and also by teachers. An area in which this is particularly pertinent is that of elementary resistive direct current circuits. Traditional physics textbook presentations, scheduled problems and tests normally channel them into exercises with formulas and with series - parallel combinations of resistors or into obtaining circuits equations by use of Kirchhoff's rules. Usually they do not invoke any phenomenological thinking or reasoning about what is happening in the various parts of a simple resistive circuit. Unfortunately also, high school students, as a rule, operate at a minimum to get by and the rules of thumb (most current will choose the easier path so it will move through the smaller of the two resistors in parallel) often used suit them well.

It then becomes imperative to attempt to develop formal reasoning in students. One way in which I have attempted to do this is through the use of interviews set up in a practical situation. By so doing I hoped to help the students to think about the happenings in a circuit. In this way the related conceptions could improve. The other purpose was to give an opportunity for the inappropriate conceptions to surface.

These sessions would involve a set of apparatus including mainly a d c supply source, light bulbs, meters and connecting wire. The instructor would draw a circuit diagram and set out to find out if the student is able to sort out what is happening. The circuits used were similar to the ones used in the diagnostic tests earlier, Figures 1 to 7 in the appendix. At every stage when an answer is given the crucial question would be: Why do you say so? When a student gave an incorrect answer the circuit would be connected and the incorrect response tested, where this was possible. Certain guidelines on fundamental principles, laws etc; would then be indicated, and the student would again be helped to arrive at a more acceptable statement of the theory.

The kinds of concepts tested were as follows:

(i) electric current before and after a resistor,
current in circuit loops, and
concepts of current flow in general

(ii) the electrical circuit as an energy system,
energy "dissipated" in the circuit components etc;
potential energy difference (p.d)

(iii) Concepts of electrical resistance

It was most illuminating to watch the reactions of students during the interviews when, after they had hypothesised about a situation, a circuit would be connected which illustrated directly and immediately that their assertions were incorrect.

The one popular incorrect statement was:

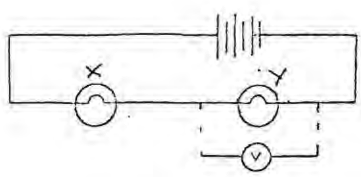
that a second lamp in series would not be as bright as the first one; that the first lamp takes a large share of the current because it is nearer the source (battery) of the current or because it is at a higher potential (use of V=1R).

This could be disproved easily by looking at a circuit which has two lamps, and noting that the brightness of the lamps is the same even when the polarity of the battery is reversed. The current could also be measured using an ammeter.

The other one was when it could be proved easily by inserting an ammeter that the electric current before a lamp or resistor and immediately afterwards is the same, thus proving that electric current is not consumed by a resistor.

The first stage of the reaction would be disbelief and an "It is a set up" attitude; or "you must have done some trick" . Later on one would sense the disappointment in them that their 'conceptual frame' does not work. This would be followed by a desperate groping for another explanation and probing the interviewer for an answer to redeem the situation. Most would pass the buck on by saying " Well !! this is what my teacher told me in school ".

Illustration: 1



Bongiwe: -- the lamp Y will be brighter than lamp X

Interviewer: Why?. Can you give a reason for this

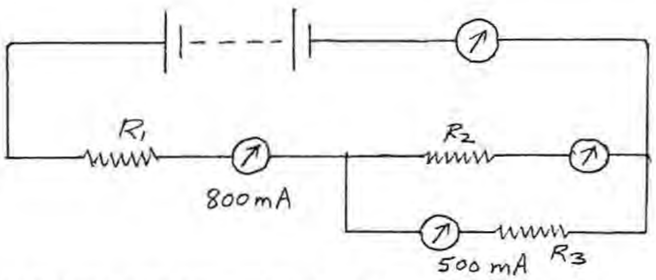
B: Because the current gets to it (Y) first
The speed of the electrons will be faster
when they enter Y, than when the electrons get to lamp X
I: But is the current not the same through the circuit?
B: No. It will be made small by the resistance of lamp Y.
It will be used first by Y and its speed will be less
by the time it gets to X
I: Let us just connect this circuit and see. O K?
...How is the brightness?
B: ...Well! .. .. Its about the same I agree.(timidly)

I: Lets now reverse the terminals .. ..
B: Why do you just turn the battery around when reversing?
Wait Mfundisi! let me do this thing myself

Well OK ! OK! But this is what I know from school

I: Let us now use the ammeter to determine the current
at every point in the circuit

Illustration 2:



Interviewer. O K What will be the current in the upper part here. through R2

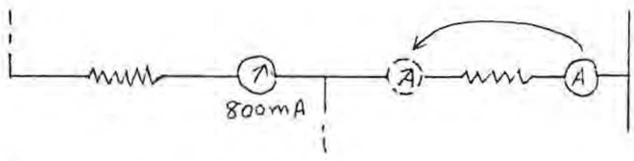
Elvis: .. It will be 500mA [Why?] .. ..
because it is parallel .. ..
the current divides here (at the junction) ..

I. .. I am sorry, I still do not understand why the current should be 500 mA there .. ..
after all it is 800 mA in this part.

E. the electricity arrives with same speed here
(at the junction)

I. Are you ready for us to try to find out? [yes] .. ..
Okay what is it?
What does the ammeter read?

E. .. .. its 300 mA .. .. (silence) .. ..
I think that it is the resistor that is
slowing down the current here.
Lets try it on the other side.

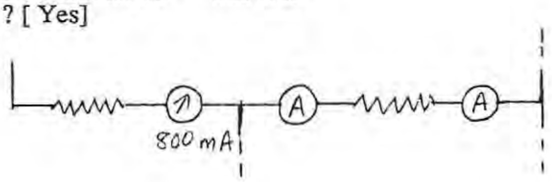


I. You want to move the ammeter to the other side? O K
What is it now?

E. it is still 300mA .. .. I dont know this .. .. ..
So the current is the same on both sides
of the resistor? [Yes] ..
can we try on the other side as well?
[Trial (on side parallel with 500 mA ammeter)]

.. Yes ?

Can we use another ammeter on this side
at the same time ? [Yes]



I. Are you now satisfied? [O K] .
You see these add up to 800 mA (500 +300) which is the same as that one there.
So current is conserved.

Now what will be the current read by the ammeter A4?

E. .. .. (some silence) .. .. can we go back to this.
Why is the current the same here? .. .. ..
Where does the electricity go to then?.
I dont understand this .. .. .. If its not used here.
.. .. so it goes back to the battery?

I. There is something that is worrying me here .. .. ..
are we talking about electric current here or electricity? [O K current] ..
The electric current can be measured anywhere in this series circuit .
It is there everywhere in the circuit.
It does not go to anywhere .. ..
It does not become less or disappear in any part of the circuit
[and in the battery?] .. .. ..
including the battery

E. How can current pass the battery when it is stored there
.. .. where does the current come from then?

I. Electric current is not from anywhere in the circuit.
It happens / occurs at all points in the circuit

E. What is the use of the resistor in the circuit then if it does not use current?.. ..
you said a lamp is a resistor, so where does the light come from then if not from the current coming from the battery.?

I. .. .. we are here concerned with energy,
electrical energy, not electric current .
The electrical energy is caused in the battery. Right? ..
.. and is given off at the resistor (or lamp) as light energy.
The electric current is the same everywhere in the circuit and is not changed during this process.

E. Where does the current go to then.. ..

I. It does not go anywhere.
It is always present at the various points whilst the circuit is closed. .. ..
the transfer of energy happens when there is a current in the closed circuit.

Anyway that is enough for today I guess. ..
Have you learnt anything ?

E. .. .. how are we supposed to know these things .. ..
I dont mean he taught the wrong things (at school) ..
I mean we didnt do the experiments to see for ourselves
we didnt understand, ...
we only just learn the formulas ..
the teacher just rushed everything.

The student was often in doubt if what he was observing was true, if the instruments themselves (meters) could be trusted. At least he now knows that electric current is conserved in d c circuits, and one hopes that his overall framework will live comfortably with this. Often in these interviews many other issues emerged which needed to be ironed out and follow ups were necessary. It could not be hoped that all things could be sorted in one sitting. It is a long process in which the student is trying often subconsciously to use his own model hoping that it will succeed sometimes without really modifying it. However we do believe that this method is successful in modifying student conceptions. A student would normally see me three or more times before other things took away his attention. In general after these it was much easier for the student to ask questions even on other work in the course. This was a bonus. One thing that emerged clearly was that these interviews were not one day wonder cures for incorrect conceptions gathered over the years. This issue will be discussed again later on in this chapter.

The one way I decided to test the effectiveness of the interview approach was through the use of the concept mapping technique. This would be used after about four interview sessions with a particular student. This number was about the average of the arranged interviews. After that the students would come informally for shorter periods.

I will now explain briefy the technique of concept mapping as I have adapted it and used it. [My introduction to this technique was from reading the proceedings of the International Seminar on Misconceptions in Science and Mathematics, Cornell Univ June, 1983 Editors: Helm, H and Novak, J]. I will not bore the reader with a lengthy elaboration of the technique and the procedures I have used to implement it.:
Naturally I had to prepare the students in the use of this technique before I could expect to get any significant results from using it. My apologies to its authors for corrupting it to my specific needs and circumstances.
After an introductory talk and discussion, the initial stage would be to isolate some concepts which are pertinent in a particular section of work eg. mechanics; and to indicate, using examples, how one could proceed to link up the concepts in a write up.
The second stage would be to ask the students to write detailed notes on each concept of the selected group indicating

i) its nature (as one understood it) and
ii) precisely in what way it is associated / related to each
of the other concepts in the group selected.

The groups of students that I used would have attempted looking at concepts in mechanics in the manner described above earlier in the year, and thus would have some kind of experience with doing concept mapping. This would normally be done in an afternoon session of free time in a quiet corner in the laboratory, and the students could work in pairs.

Ths assignment was introduced in the following manner:
In the class discussion we have identified the following concepts as being the key ideas when dealing with direct current electricity:

Electric Current
Electromotive force
Potential difference
Voltage
(electrical) Energy
Resistance,

Write some notes on each one of these to indicate

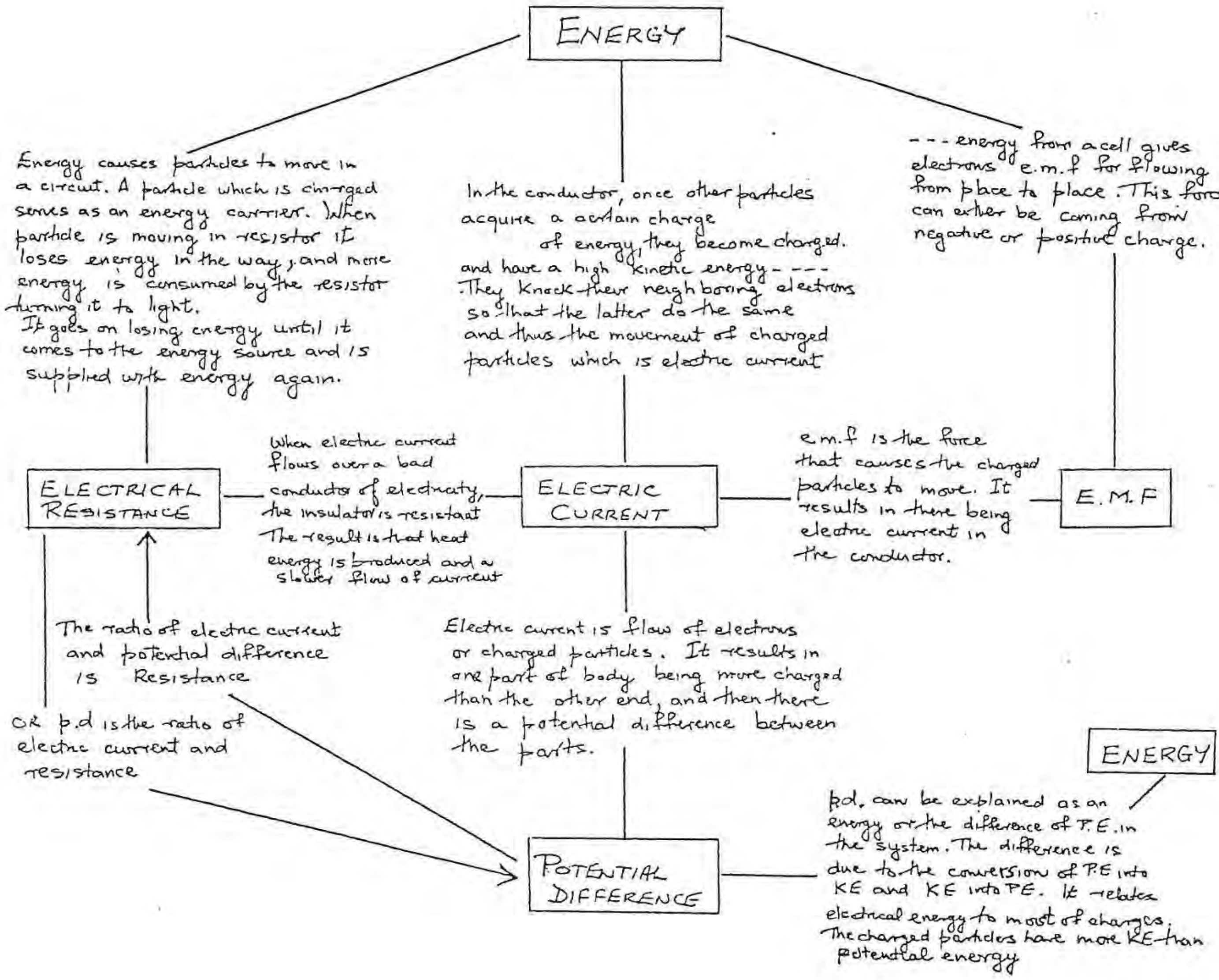
i) the nature of each concept
(as you personally understand it)
ii) in detail in what way it is connected or related to each of the other concepts.
In your explanations you may use any other information, words etc; that you have learned in your study of science or elsewhere.

The exercise was arranged for the week preceeding laboratory work on electricity and it was the general understanding / projection that whatever came out of the analysis would be useful in designing practical work that could benefit the students by reinforcing appropriately their conceptual frameworks.

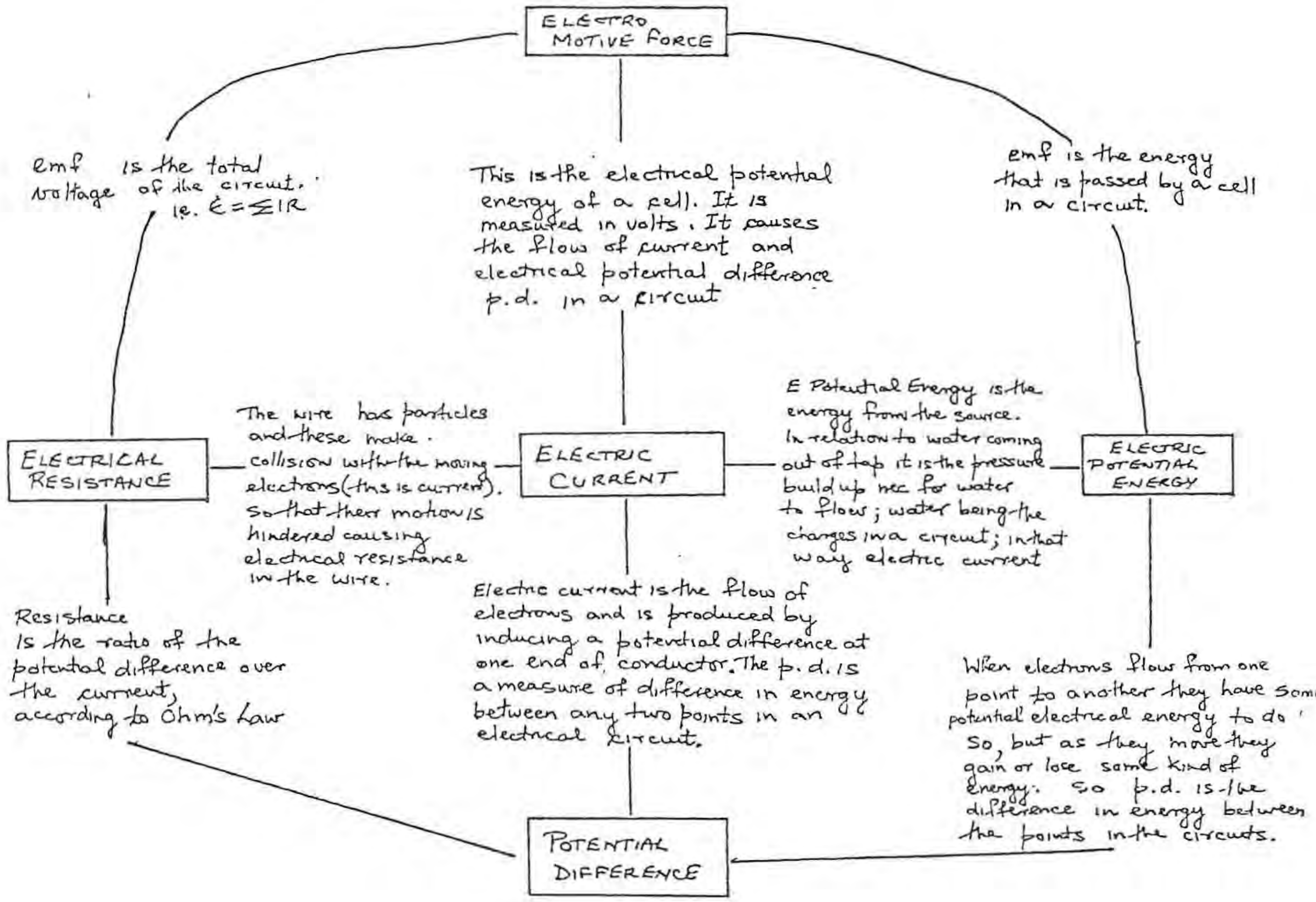
I selected students from these groups for the personal interviews and went through the exercise described earlier in the paragraph with them. I would then expect them to make a second attempt at concept mapping. In this way I was able to compare concept maps done before and after the interviews.

Below follows a typical example:

CONCEPT MAPPING – BEFORE



CONCEPT MAPPING — AFTER



I have included the particular concept mapping A (Before) because it was typical, in the sense that a large number of students gave similar answers, and the concept mapping seemed to be more elaborately detailed when compared with others.

In the first mapping the student gives some incorrect impressions about d c circuit phenomena :

One of these is that if a particle has charge then it has energy; that after passing the battery, the particle has become charged in the sense that it now possesses (electrical) potential energy which it did not have before, and moves along pushing the others hence dissipating this energy. The particle has been "pumped" full of energy and therefore it is charged. This compares with the secular understanding that when a person is charging a flat battery she is giving it (pumping it full with) electrical energy, and that is why one is able to get more electricity from it.

Another incorrect conception revealed here is that the energy from the cell gives electromotive force (=force) to the electrons when they pass through it; that the reason these electrons move around the circuit is because they have this force. Electrical energy is transferred from the battery to each of the resistors in the circuit sequentially.

The student has the impression that there are parts in a resistor which have more charge than other parts and therefore that is why there is potential difference between them and the other parts which have less charge; and that electrons (and hence current) then flow between the points.

In her picture the links between loss of kinetic energy and gain in electrical potential energy are very direct . The (electrical) potential energy of the electrons (received in the cell) is equal to the kinetic energy.

Her model of resistance is based on the congestion of electrons as they pass through a resistor and therefore the collision and rubbing with each other causing friction and heat, sparks and light.

There are also a couple of unacceptable conceptions that I would like to comment on: The first one is that a particle is charged when it has received more "potential" energy. There was plenty of evidence of this view.
In the interviews students would put the argument that when a battery is flat, one has to charge it, and after this one could get electricity [=current] from it again: or a soldier charging the enemy normally has lots of energy, and so on.

This life world meaning of charge is not uncommon for students who do not have a proper conceptual frame, and who are not familiar with English language metaphor, a problem highlighted earlier.

Secondly, the problem with potential energy (electrical) changing to kinetic energy rears its head. This follows from

loss of (gravitational) potential energy = gain in kinetic energy

in conservation of mechanical energy for a system under the action of the (conservative) gravity force only.

I interpret most of these incorrect models as attempted justifications of the incorrect conception that electricity (=current) is lost or "consumed" at the resistor. My experience has been that once one has demonstrated in an experiment that electric current is not less on the other side of the resistor, the students abandon the incorrect conceptions listed above.

The problem of "charging" a battery to get more electricity from it, and its getting flat afterwards is a real one.

I have pointed out that the break down of the chemical processes and the rise in the internal resistance of the battery leading to a flat battery should be considered separately in the operation of a battery. This matter is strictly speaking not part of the conceptual model of the simple electric circuit. When the battery is operating at the steady state it is not getting flat, but is giving a constant value of energy per unit charge [emf] to the electric circuit system by maintaining the field in the conductor. I have often argued for the need of continuous input of energy at the battery by using other examples of current generators like the Photo-electric cell, the solar cell, the bicycle light generator.

In the photo-cell the light has to shine continuously on the cell for it to operate; similarly in the bicycle light-generator the wheels of the bicycle must keep on turning for the light to be on; suggesting that energy has to be continually input in both these instances for the 'cells' to work.

The second concept mapping is by the same student after a consultation. To me it does seem to be an improvement on the first one.

Improved picture:

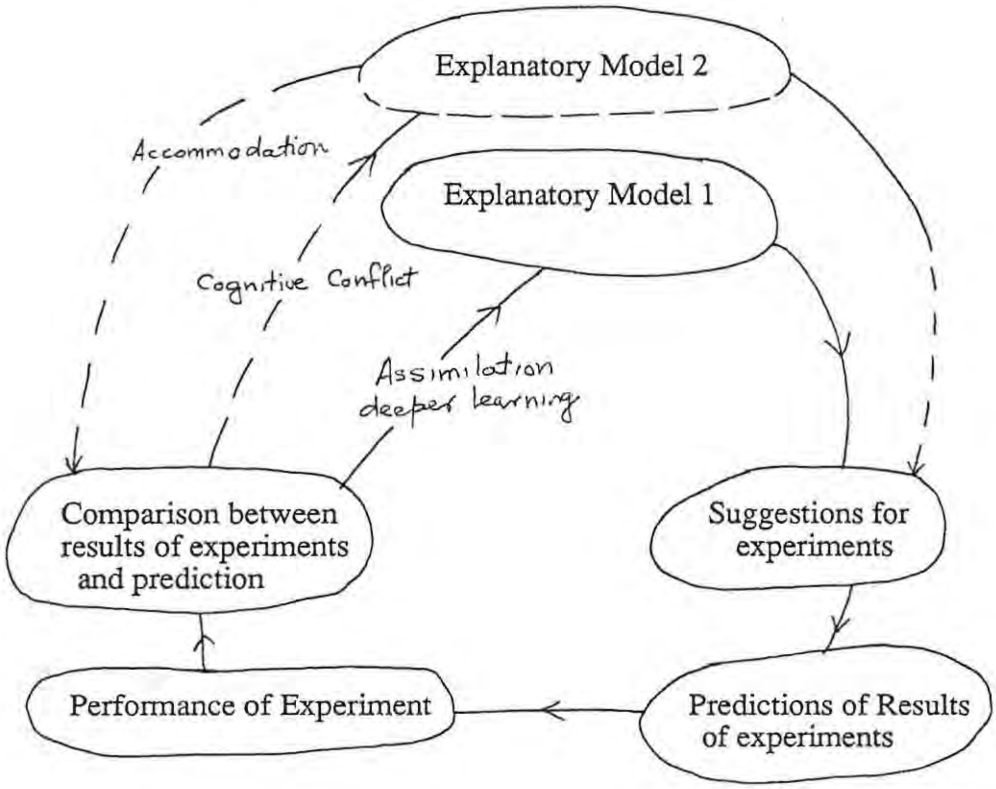
In the second mapping the picture is improved in the sense that electromotive force is now no longer considered to be a force but as the potential energy of the cell; the student has established the relationship between emf and the sum of the pd's.

The electric current however is still defined as the flow of electrons and not as a rate of flow of charge.

There is an improved conception of resistance which takes into consideration the positive ions fixed in the lattice positions of the conductor. The collisions between flowing electrons and these is implied more forcibly and so is the idea of the gained kinetic energy (by electrons) being lost to the conductor between any two significant points in the conductor.

However, it is not my argument that perfect explanations have come out in this second mapping. It does nevertheless illustrate, even if in a limited sense, the effectiveness of the use of interviews, in a laboratory setting, as a strategy for correcting and accommodating misconceptions.

My argument is that the student has learned something. There has been a transition from one way of perceiving phenomena to a new way that differs qualitatively from the first one. Some disagreement has occurred between how she thought things were and what she has observed them to be, even according to her on predictions, . There has been a cognitive conflict. Along the route her previous cognitive model has been challenged through the interactions and activities that happened during the interview. During this time she has had to find a new model or to modify the existing one. Hopefully the new way of looking at things or concept is more comfortable in her mind in its relation to other concepts and to earlier experience. This model of learning is depicted in the chart below [Karrquist 1984]:



If the newly constructed model can be used successfully to explain the previously inexplicable experiment, and if the student can use it successfully to predict the results of new (and old) experiments, he will probably accommodate ie change his old model to the new explanatory model. There is also a chance that some other related incorrect conception may benefit from this exercise; and the student changes and modifies it also to fit into the new way of looking at things.

In the future the student will be more ready psychologically to change other alternate conceptions when their explanatory powers have been effectively challenged. He will be more sensitive to the views of others (including teachers) and attempt to relate his own views more closely to experimental evidence. I believe that these activities of the mind have great value even in the intermediate stage. They form part of the process of science education because they make the student realise that a model is as good as its explanatory powers. If it does not satisfy observation then it has to be abandoned at some time, if it cannot be improved. Students come to understand that part of the scientific enterprise is a search for the most powerful explanatory models of physical systems; and this is important for students to realise.

6.1.1 Some specific intervention strategies:

In the paragraphs below is a brief outline of some approaches that may be of use to discourage some of the major inappropriate conceptions which I have found to exist with students. I cannot guarantee success or present conclusive evidence that these approaches are necessarily the ones that will do the job under all circumstances [because of the nature of the process of conceptual change]. Along with the proposed strategies I have presented arguments that I hope will convince the reader of the corrective value of the strategies. Evaluation of the success of conceptual change is normally over a long period and it is not possible to produce conclusive evidence about the correction of inappropriate conceptions in a short time period.

In the experimental approach our experience is that we can use cognitive conflict successfully; ie put the student in such a situation that his own ideas are inconsistent with his experimental observation and with logic. In so doing we hope that the student will change his view and adopt a more "correct" view. Thus the first condition to use cognitive conflict is the knowledge of the student's ideas.

Basically the student has to state his knowledge [come out with his view] publicly about, for example, anticipated happenings in an electrical circuit.

(i) "Current is consumed " conception

The critical experience here is to present the student with a simple circuit and to ask him to predict the electric current magnitude on either side of the lamp or resistor, in terms of his own prefered model. The student can then be made to take measurements of the current, using an ammeter, in the positions indicated in the circuit diagrams below. When he makes these observations he will become familiar with the fact that current is the same before and after a resistor.

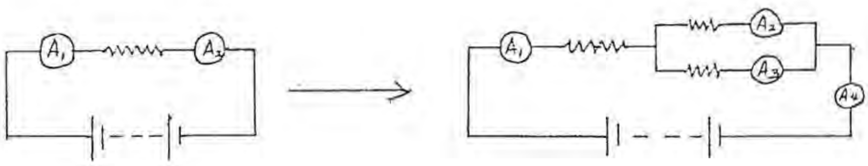


Figure 6.1

(ii) "Current is shared [and used] by all the components in the circuit"

In the circuits in (i) above and other similar ones, it is important to determine the current at the point where the leads are connected to the battery, 'after the current has passed through all the components of the circuit', in order to "prove" that there is still current at this point. The student will hopefully realise that current is not 'shared and used' but actually "occurs" at all the components of the circuit.

In dealing with most inappropriate conceptions of current the instructor has to be constantly mindful that most students have basically inherited from their background the fluid metaphor intuition of current [Johsua and Dupin 1984]; namely, a model of a flowing current which is at once a fluid of matter and a fluid of energy. The problem for the student [as he sees it] is how to explain that the [material] fluid conserves itself and, at the same time, as energy [the fluid] 'exhausts' itself on passing through a resistor as evidenced by the light, heat coming off the bulb and by the wearing down of the battery in time.

(iii) "Current is a constant and is *supplied* from the battery"

An attempt to correct this incorrect conception may be made initially by arranging two lamps in parallel:

Students should be asked to anticipate the brightness of bulb 1 when 2 has been taken off.

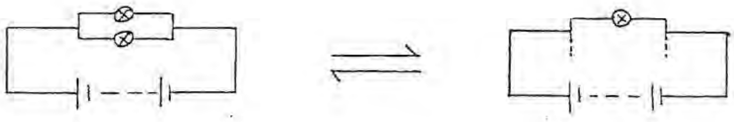


Figure 6.2

A frequent answer is that bulb (1) will shine twice as bright when bulb (2) is removed, because all the current is now going to it.

Eventually I think the observation should be done with ammeters and not just lamps. A good tactic, as stated earlier, is to wait until the student's particular theory leads to the prediction of an observation which turns out not to be correct. Since he has a theory he will be able to give an answer and the waiting will not be long.

In a remedial class situation the individual members of the whole class could be asked to make a prediction and a count / vote taken before the measurement is actually taken. Class discussion would probably take place after this and the overwhelming evidence and peer group pressure could be used effectively in influencing the change of the conceptual model to the acceptable one.

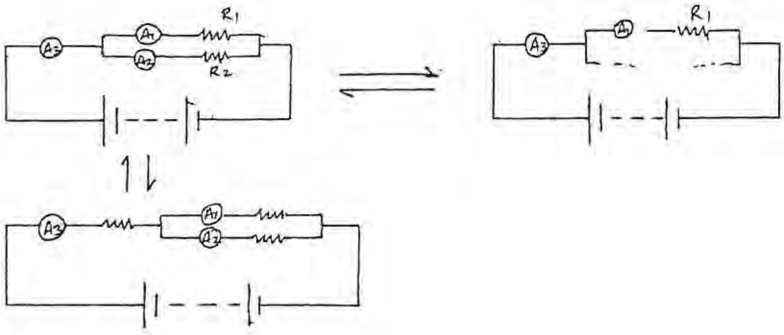


Figure 6.3

In the circuit above the student must be made to predict what the current reading will be in A1 and A3 when the resistance R2 is removed. It is also important that the students must be convinced that the meters do not perturb the system.

(iv) "Current cannot pass through the battery because
the electrodes are not connected"

Attention of the student could be drawn to the flow of current through electrolytes [eg Copper Sulphate solution, dilute acids etc] where there is obviously no metal connection. This should not constitute a problem as the conduction of electric current through solutions in water of common salt, copper sulphate, dilute acids is already part of the scope of work done in standard 10 chemistry classes.

My criticism of present research is that it is not particulary critical of the fluid flow metaphor [Duit and Jung 1984], neither is it analytic of it. The research also does not direct thinking about the question of the charging of a "flat" battery to get more electricity [=current] from it; the storing of electrical energy in the battery etc . An attempt to address this issue could be along the following lines:

In a charged battery [wet cell] certain chemical reactions which release energy are ready to take place. The resulting energy only becomes electrical potential energy when it is input to maintain the electric field in the conductor [the p d across the conductor], or the emf of the cell. Whilst the circuit is operating these chemical reactions happen in the battery and continuously cause charge separation, thus maintaining an electric field that would normally deplete. In this way chemical potential energy is transforming into electrical potential energy [input] . The chemical potential energy set up [that the chemical reaction has the potential to happen] is not part of the electrical energy system although there is continuous [electrical] energy input from it as the circuit system operates.

When a battery becomes flat essentially it is as a consequence of a breakdown of the chemical processes in the cell, resulting mainly in the increase of the internal resistance r of the battery. The emf of the cell [the measure of energy input into the electrical system] has not become less. It is the potential difference across the cell [$V = E - I r$] which has become dramatically lower. We know, of course, that this potential difference V indicates the actual power output of the battery.

(v) "Voltage is supplied as a constant by the battery "

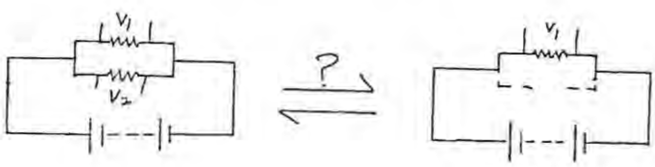


Figure 6.4

The students may be asked to anticipate what the voltage reading V1 will be if R2 is disconnected, and vice versa.

(vi) "The conductor near the [positive side of the] battery takes a larger share of the voltage [and hence bigger current] for itself; the voltage as measured diminishes along the line as it is dissipated [used] by the resistors."

An elementary approach to this inappropriate conception would be to arrange two or more equivalent lamps in series.

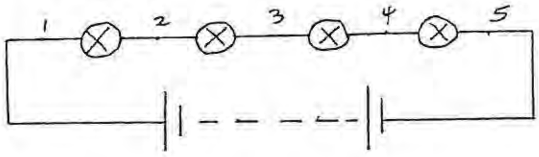


Figure 6.5

If the first lamp took a larger *voltage* for its use it would always have to appear brightest. The demonstration would show that the brightness of the lamps in reality does not get affected when the polarity of the battery is reversed, or when the individual lamps are interchanged.

Two small value resistors [one twice the value of the other] could also be arranged in series in a circuit, and the pd across each actually determined using a voltmeter.

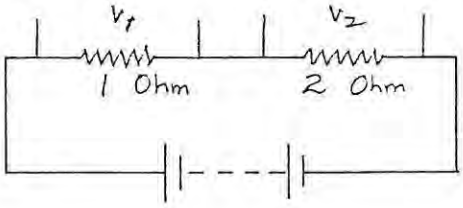


Figure 6.6

Even when the polarity of the battery is reversed the *voltage* of the 1 ohm resistor is always smaller than that of the 2 ohm resistor; also when the two are interchanged.

For most of the strategies listed above, it is very important to have an application phase if conceptual change in the permanent sense is to be brought about. Switching to new ways of understanding will not easily come about unless the benefits of the new conceptual models are perceived to be worthwhile. In the application phase the students would be exposed to situations in which they are encouraged to test out their new beliefs by first predicting and then observing the determined values. For example one could start off simply by changing the values of the resistors in the circuit and asking the student to predict the value of the electric current at different points. The student will then gain confidence in his acquired abilities. If this procedure is adopted they are more likely to be convinced of the necessity of the new models of thinking.

There are many other inappropriate conceptions which will manifest themselves in different ways and the scope of this work does not make it possible to cover all circumstances. The main idea was to indicate possible ways in which we as instructors could address the conceptual problems of students using the personal interview.

In general once an instructor has become aware of a predominant incorrect conception it should be possible to design, and integrate into his lessons, an instructional sequence which can be used on the whole class in order to address the inappropriate conception. I have proposed the "electric circuit as an energy system" framework of earlier, for example, for similar reasons. Shipstone and Gunstone [1984] and Shipstone [1988] discuss in detail an instructional sequence to get rid of the source-consumer model view of electricity.

Osborne [1983] has used the analogy of the heart [as a pump] and the blood system to model the electric circuit; Shipstone and Gunstone [1984] have used the boiler and radiator hot water system, whilst Johsua and Dupin [1987] have tried to make an analogy centred around a locomotive going around a track. From these reports, I am unable to make an evaluation of how well these analogies have improved the understanding of their students of the electric circuit. Personally I would be cautious of using these forms of analogy with mature students because analogies often raise more questions as they answer others. However I do accept that analogies may also be used to cultivate an improved understanding if the students relate to the analogies.

6.2.0 Use of laboratory Interactive Exercises [practicals]:

It does seem that the traditional approach used in most books at the school level, and at university, is to provide ready made tools without giving the student a chance to reflect on the reason for the existence of these tools. The idea that problems arise as a result of discrepancy between the expectations and the observations of the researcher is usually absent. Curriculum designers do not usually / generally show an interest in the problems which gave birth to the conceptual tools, but in providing the latter to the students and in training them on how to use them [Otero 1985]. One can see how this attitude may be perpetuated by the approach of many teachers, that science is a collection of *answers*, explanatory concepts, a fixed body of knowledge to be imparted to the student, which we have mentioned earlier.

Whilst there can be no hard and fast rules in this matter, certainly there is some merit in the inductivist structure in which empirical knowledge is introduced first (even if subtly); and following upon this the concepts which interpret the observations. Most students do not learn to solve problems by applying abstract concepts to a situation. In fact they compare the situation being analysed to a situation handled earlier. It is more likely that students do not really learn concepts; that they learn how to deal with certain situations. The conceptions which they have are not abstract but are flavoured with the characteristics of the situations handled during the learning process.

Concepts in science should be normally introduced as logical possibilities which could enlarge the content of a discipline, and usually as a response to an outstanding problem. This approach seems to be particularly suitable to the study of simple electrical circuits, where situations to be studied can be generated in a laboratory situation without much inconvenience.

According to Ausubel's theory of learning [1978] one would expect that students who are exposed to answers before having been given the problem will develop more arbitrary links to their pre-existing knowledge than those who are exposed to the conceptual explanation only after having meaningfully learned the problem (or issue) which determined its appearance. In addition, it is very important for students to understand that scientific concepts result from an interplay between a theoretical framework and empirical data. This is not always clear in school textbooks. Hiding this from students results in presenting artificial constructs whose only justification supposedly lies in the facts or phenomena being explained at that time. In general physics instruction has severe difficulties in convincing students that, in some situations, physics notions are more appropriate as explanations than notions stemming from everyday experience [Duit 1984]. Students do not perceive and analyse a situation in conceptual terms. Most connect functional properties to a situation; they try to think of some use for the whole thing. That is why the consumption of electric current overpowers ideas of conservation of current; why (in their frame) current must be used in a resistor, sacrificing even conservation of matter (electrons) and charge. Whilst it can be convincingly argued that the "facts" do not determine the *givens* of the experience, conceptual knowledge as established theory is necessary to introduce "order" in the *givens* of experience.

In the form of scheduled laboratory activity we have used simple circuits involving stable direct current power sources, resistors and bulbs, to provide a means by which students could be led to an understanding of circuits and related phenomena; understanding being taken in the sense in which the community of practising physicists understands. The underlying aim of these laboratory activities was to give the student a variety of situations to confront, in order to infer general properties of a circuit. Another aim was to design a laboratory activity which would teach students some general thinking skills of the kind generally used by physicists.

I felt that for the majority of our student intake, because of their educational and socio-cultural background, there was a need to present natural phenomena studied in electricity directly to the student. These phenomena are normally removed from personal experience. Such laboratory experiences should provide the students with an intuitive base upon which the abstract concepts may be built or restructured. Furthermore without concrete experiences, students have difficulty in generating interest and enthusiasm for the topics being discussed.

The laboratory activities should give the required experiences and supply the necessary checks leading to the formation of guiding principles. Hopefully the situations depicted in the observations would not only help to re-inforce acceptable conceptual models, but also help students choose from any alternate models the "correct" one on the basis of experimental evidence.

6.2.1 Activities on concepts of electric current and flow, and associated concepts:

All the students involved in these activities had at least done standard 10 physical science and would have come across the concepts of electromotive force, potential difference, voltage, electric current, charge, electrical resistance etc; and all related representations in the theory of direct current, at least two years before entering university.

I chose to make use of (un)standardised 5 watt resistors, produced and obtainable commercially, in place of the torch bulb. It was more convenient to quantify the electric current in the circuits using milliammeters and voltmeters, rather than to judge it from the relative brightness of the lamps. The determination and comparison of brightness of torch bulbs introduces human error and my experience was that it was not always obvious that one bulb was slightly brighter than the other one, especially if the other was no longer on. Also, it is not uncommon for bulbs with the same rating to appear to be of unequal brightness and this tends to confuse the issues.

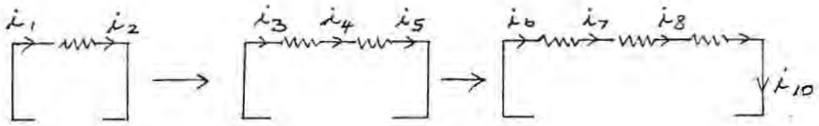
It must be emphasised that these were scheduled as laboratory interactive activities and not experiments in which a definite outcome or result on the part of the students was to be expected. Normally students worked in pairs in an informal atmosphere with the instructor available for consultation. Here follows a brief description of the laboratory activities organised.

===========================

A.

Interactive Activity: A.1

Figure A a b c



1. Connect the circuit according to diagram in Figure A (a)

Write down, and hand over to the instructor your prediction of how the electric current at points 1 and 2 will compare :

Will i_1 be greater than i_2

or i_1 will be equal to i_2

or i_1 will be less than i_2

What will be the effect on the values of i when the terminals of the battery (emf source) are reversed?

What will be the effect (on the currents) of short circuiting the resistor by connecting a thick wire between points x and y ?

Write down your answers to the questions asked above, and hand them over to your instructor.

Proceed to determine the current at the points 1 and 2 by inserting an ammeter at each point and test your assumptions/predictions.

Compare your predictions with actual findings and DISCUSS your conclusions with the instructor.

Interactive Activity: A. 2

Similarly, adopt the same procedure for the circuit depicted in Figure A (b) and compare i_3 i_4 and i_5 .

(Start off by writing down the expected relationship between the values of i_3 , i_4 and i_5 .)

Connect the circuit according to the diagram in Figure A.(b)

Measure the current i by inserting an ammeter at the point.

Compare i_3 with i_4 and i_5 .

Measure i_4 and i_5

Reverse the terminals of the battery and measure i_3, i_4 and i_5 again.
Discuss your findings with the Instructor.

Interactive Activity: A.3

Use the same procedure for the three resistors connected in series of circuit in Figure A (c).
What do you expect the value of the current i_6 , i_7 and i_8 to be?

Compare the values of i_1 , i_2 and i_3 with the total resistance in each of the three different circuits a b and c .

Discuss your findings with the Instructor if your findings do not agree with your predictions

----

Comment:

The first of these activities, it was hoped, would demonstrate

(i) that the electric current is the same at every point in a series circuit, the conservation of current
(ii) the effect of a short circuit
(iii) the relationship between E and the sum of the iR's, E= iR, when there is one resistor in the circuit, and when there are two or three resistors in the circuit.
That the sum of the iR's totals E in a series circuit.

Typical values:

E = 1,5 volts

(a) i_1 = 370 mA i_2 = 370 mA

(b) i_3 = 190 mA i_4 = 188 mA i_5 = 190 mA

(c) i_6 = 122 mA i_7 = 122 mA i_8 = 123 mA

E = 3 volts

(a) i_1 = 700 mA i_2 = 700 mA

(b) i_3 = 350 mA i_4 = 350 mA i_5 = 350 mA

(c) i_6 = 235 mA i_7 = 235 mA i_8 = 235 mA i_{10} = 235 mA

Hence

V = i R

Interactive Activity: B.1 and B.2

Comment :

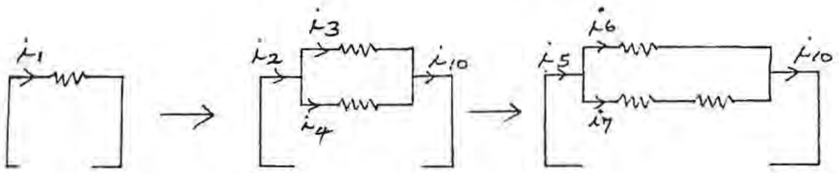
A similar type of procedure was given for the building up of the simple circuits as shown in Figure B leading to the determination of relationships between

(i) the current i_3 and i_4 with i_2 in Figure B (a),

(ii) the current i_6 and i_7 with i_5 in Figure B(b)

Figure B

(a) (b)



The second activity (involving Figure B) would re-inforce the idea that

(i) the sum total of the incoming current at a junction is equal to that of outgoing current

$i_2 = i_3 + i_4$ and $i_5 = i_6 + i_7$

(ii) the effective resistance in the combination in circuit b is less than that in circuit a, since

i_2 is less than i_5 and also i_7 is less than i_6

Typical values:

E = 3 volts

(a) $i_1 = 700$ mA $i_2 = 350$ mA
$i_3 = 350$ mA $i_{10} = 700$ mA

(b) $i_5 = 700$ mA $i_6 = 465$ mA
$i_7 = 235$ mA

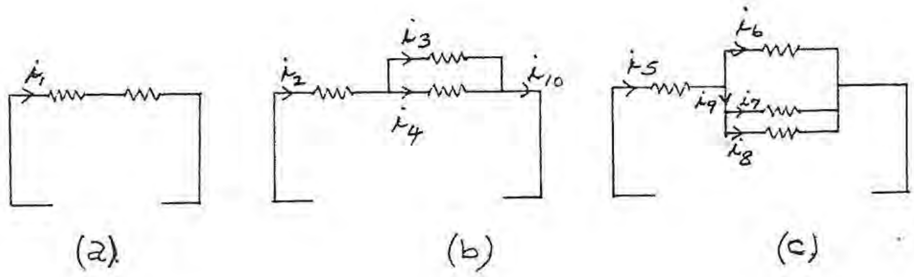
$i_{10} = 700$ mA

========================

Interactive Activity: C. 1

Similar procedures were adopted for the set of circuits in Figure C:

Figure C



In activity C the same kinds of ideas as in the last exercise would be re-inforced namely:

(i) current into a junction is equal to current out of the junction

$i_2 = i_3 + i_4$ and $i_5 = i_6 + i_7 + i_8$ and $i_9 = i_7 + i_8$

(ii) the effect of adding a resistor in parallel is to

reduce the equivalent resistance of the circuit,

hence on comparison

i_5 is greater than i_2 is greater than i_1

Typical values:

E = 3 volts

(a) $i_1 = 350$ mA $i_{10} = 350$ mA

(b) $i_2 = 460$ mA $i_3 = 225$ mA
$i_4 = 235$ mA $i_{10} = 460$ mA

(c) $i_5 = 510$ mA $i_6 = 170$ mA
$i_7 = 170$ mA
$i_8 = 170$ mA

and $i_9 = 340$ mA $= i_7 + i_8$ $i_{10} = 510$ mA

===========================

6.2.2 Activities involving potential (energy) difference relationships:

The students were assisted to measure the potential differences across each of the resistors in the circuits used in the previous activities on electric current; and to establish the relationships.

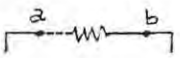
Comment:

The mathematical relationships of the various pd's were fairly easy to demonstrate using the same circuits as shown in Figures A B and C.

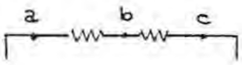
Typical results:

Figure A:

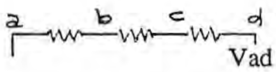
Typical values:

(i) 

Vab = 3 volts

(ii) 

Vac = 3 volts
Vab = Vbc = 1,5 v

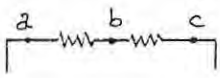
(iii) 

Vad = 3 volts

Vab = Vbc = Vcd
= 1 volt

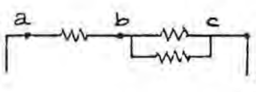
Figure C:

Typical Values:

(i) 

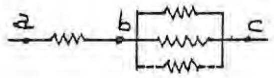
Vab= 3 volts

Vab= 1,5 v and
Vbc= 1,5 v

(ii) 

Vac= 3 volts

Vab= 2 v and
Vbc= 1 v

(iii) 

Vac= 3 volts

Vab= 2,25 v and
Vbc= 0,75 v

6.2.3 Activities involving electrical resistance:

With the above circuits exercise was given in the calculation of the equivalent resistance using V = I R for the resistor in series and parallel arrangement. The students were asked to compare the values of R.

6.3.0 Additional Practicals Strategy :

A number of researchers have developed teaching strategies that they believe facilitate the process of conceptual exchange [Posner 1982]. The strategies usually involve one or more of three phases which go under a variety of appellations. Essentially according to Pines and West [1986] the three main phases are:

Awareness
Disequilibration
Reformation

The awareness phase involves experiential and clarification manoeuvres in which the teacher provides a range of activities, followed by class discussion, designed to elicit and highlight the existence and nature of competing points of view.

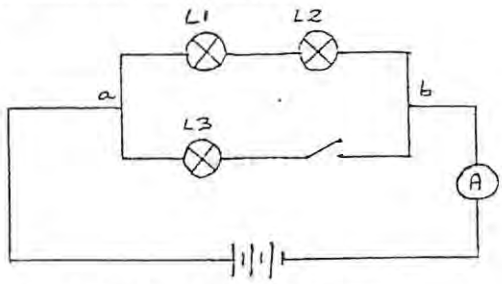
In dealing with electricity circuits in formal practicals I have essentially used this approach. Whilst the students are doing a scheduled practical, they have to commit themselves, through various inputs, to some viewpoint or other on some conceptual aspects of the scope covered by the practical. Below is a sample grid of one of these practicals activities :

Page 59

PART H - MEASURING CURRENT :

Connect up the circuit below with an ammeter A in the circuit

(a) with switch S on
(b) with switch S off



In (a) and (b), measure the current [on A] and the potential difference between the points a and b. Note the brightnes of the lamps.

OBSERVATION :

a. L_1 and L_2 are dim

b. L_1 and L_2 become brighter
L_3 is not glowing

ACCOUNT FOR YOUR OBSERVATION :

Comment on the brightness of each of the lamps L1, L2 and L3, before pressing the switch.

a. At the point b, the voltage is divided, and for L_1 and L_2 the current is the same.
for L_3 the voltage is not divided, that is why L_3 is brighter.

b. Since the Voltage is not divided at point b in this case there is a greater current flow at L_1 and L_2 thus the brighter glow of L_1 and L_2 {compared to a. part}.

The instructor would then have an opportunity to read through these comments ostensibly as part of evaluating the laboratory effort of the student. The inappropriate conceptions would then be catalogued by the teacher and filed, for use before the next scheduled laboratory exercise. In the discussions afterwards the different conceptions would be openly discussed and evaluated in small groups, with the guidance of the instructor. The inappropriate conceptions would then be isolated, the acceptable ones validated and reinforced through argument and evidence.

Illustration:

Miti no Magudu:

Miti: Mfundisi... (mna) I dont understand this

Why do you say that what I have written here is wrong?

(Andithi) Isnt it that these bulbs were brighter than
this one?

I. Yes .. .. I think that we should discuss this
Please call your working partner and come along with me

S. .. .. It's the voltage that divides Isnt it? .. .. ..
The voltage is supplied by the battery

I. In what way do you mean it is supplied?

S. .. a battery gives 6 volts. then this is 6 volts.
The 3 volts goes to this lamp and the other one to
these lamps (in series).
And these two get a small voltage of 11/2 volts each.
This (single) one gets 6 volts
That is why it shines brighter.

I. Voltage is not supplied by a battery.
I do not think that you should use that word as
a habit here. It tends to be confusing.
Lets talk more about emf and potential difference .. ..

How do you measure this voltage anyway?
Show me how do you get it?

<u>Other student</u>: OK OK I think Eh Uhm!
I think that we are wrong here.
I think that we get the voltage by
using V=IR .. Neh?
It's the current that comes from the battery
.. ..

I. I am afraid that's not quite correct . .. .
We will try to come back to this point later .. ..
Sorry .. O K?

Now let's get back to the question. How do you measure voltage ?

S. Using a voltmeter (show me) .. .. like this

I. Can you measure voltage with one connection ? (No)
You try to measure the voltage across this lamp

S. .. It's 6 volts .. ..(and across these lamps ?) ..
It's also 6 volts
O K ..it's 3 volts and 3 volts in (each) these lamps (in series)

I. Now I want you to think carefully .. .. before telling me what the voltage will be across here (two lamps in series) if we remove this lamp.

S. Well .. .. it should be twice .. well about 6 volts for each in the parallel parts.
++ .. it will be 12 ..
All the volts will be going to this side now

I. Remember I said volts dont go anywhere. .. .. we agreed that volts is a measure of something between two points.

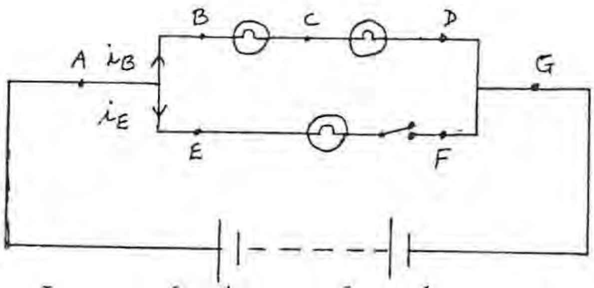
O K Let's separate this lamp out.
Would you like to measure?

S.1 .. well it's 6 volts
(across both lamps L1 and L2) .. .. ..
I dont know .. .. and its 3v for each lamp here .. ..
Mhm! .. ..(some silence) .. .. No Neh?
(After a moment)
I think you are right (to his partner in the expt)
Its the current that divides .. ..
That's why that lamp (L3) will be brighter than these (L1 and L2)

S2. (His partner, friend) : Yha! .. Yha! .. It will be the current .
It will be half for these two lamps.. ..
because its shared by them

I. No, the current is not shared.
It does not go to each lamp as such .
You can find current even at this point beyond the lamps .. ..
O K Let's start to use the ammeter.. .. and measure the current at each point. (A B C D E F G)

Do you want to check it ? (..Yes..)

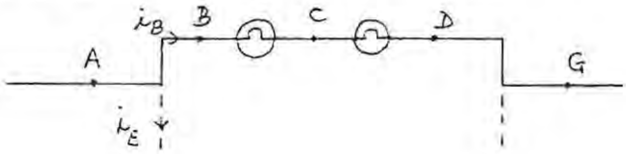


S1. .. . yes I can see .. there is current also on the other side of the lamp..

I. The current here depends on the potential difference across this lamp and the resistance R of it. .. ..
the current does not begin in the battery .. ..
There is some current everywhere in a circuit

S.1 Yha! But this thing does not prove anything .. ... .
The current is still half and half in these parts here. (B and E)
Only half goes to the lamps (L1 and L2) .. ..
the current going to this one is 80 mA and to that one also 80 mA .. .. and to this one its 160 mA ..

I. .. ..O K .. .. Now I want you to think carefully first.. ..
I want you to tell me what the current will be in this part if we remove the single lamp (L3).
Use your argument.



S.1 It will be double . No I am not sure here. Eh!
At least .. .. It will be the sum of these two here .. . .. more than this one (i B)
All the current will be going to these two lamps (in series) now
Its going to be what the current was here (point A) .. ..

I . Would you like to measure it. Please ?

S.1 .. .. (more silence and fiddling) .. No
There is no change .. (in iB)
.. .. .. Mhm .. .. Hey! .. these things beat me .. [ziyandihlula]
Kanti? What is it (exactly) that divides?
How is current shared?

I. .. .. each series circuit part is like being connected separately to the battery ..
the current in the lamp depends on the potential difference across the lamp and the resistance R of the lamp.

S.1 I am really confused now .. .. ..
O K I can see that voltage does not
divide . .. .. and now the current also .. .. ..
I think that my mind is tired now.
I will have to go and think about this thing.
I will be alright maybe.

I. Please do come back when your thoughts are clearer,
and we will talk more about these things.
I will try to help you along to an acceptable way
of looking at these things.

There are at least two stages in this interview where the student's view was challenged and the outcomes of his observations were contrary to those expected. At this stage he has to construct in his mind an alternative model or modify the old one. He is probably motivated to listen to alternative suggestions. It is important that the student must have this cognitive conflict, because it provides evidence about his framework, that it may not be correct.

The interview has probably demonstrated to the student successfully that voltage does not flow and is not consumed by a resistor; and he may well accept that electric current is not shared (and used up) by the components of a circuit, since it is observed to be equal on either side of the lamp. However there was no doubt that he had not fully assimilated the concepts involved. We do not expect students to throw away their views in one session. If it seemed that he was doing this, he would not have learnt much. After a few times he will have assimilated some of the related concepts into his cognitive structure.

If one looks more closely at the interview a few characteristics come out:

At first the student stands his ground and argues for his thinking model, but quickly grabs onto his friend's model when his seems to fail. Towards the end when the current-is-shared model lets him down he is indeed without recourse and things seem to be going too fast for him. He would rather retreat and quietly rearrange his thoughts.

I encourage this because I accept that it is not a matter of telling a person the correct way; they have to internalise it and assimilate it into their thinking. This may take some time and further reinforcement. Sometimes students do get the feeling that the interviewer is just setting them up by exposing them to the "correct" input, so that they may accept one particular view even if it is just in good faith. It is important for the student to make up his own mind and to test his hypothesis, without much interference from his teacher etc; The better strategy is not to seem to take sides, and to allow the experience (experimental observation) to show it to him. With the guidance of the interviewer he has to search for a satisfactory model to explain things. He will be led to recognise the need for interplay between experimental observation and a theoretical framework in physics. There is also the question of how sufficiently ready and prepared I was to respond to him. At one stage (line marked ++) I could have pinned him down on why the volts were now 12 volts (6+3+3) when we had set out with a 6 volt battery. The better strategy I feel is to follow cautiously the flow of his thoughts. In this particular case there was the complicating factor of having two of them at the same interview.

So the road of conceptual change is not a plain one. Shipstone [1984] has reported some successes with this method, but he concedes they are / were not statistically significant. He suggests that if the students are exposed to further experiences there is a very good chance that this method will succeed. Other people working in this field have made similar observations. Researchers in this field are becoming increasingly aware that conceptual change takes time and that it is important to counter the intuitive ideas that are reconsidered at regular intervals over a period [Closset 1984; Cosgrove et al 1984; Osborne 1983]. This may have implications for curriculum design.

Johsua et al [1987] warn that students' conceptions have a great capacity for logical adaptation, that they often develop so as to include new experiences while at the same time remaining fundamentally incorrect from the point of view of physics. It is even possible that the student may accept the appropriate model for incorrect reasons. Although he may the get the gist of concept, it is possible that it will not necessarily be because he has adopted a scientific viewpoint.

One very important aspect about this situation however, is that the student clarified and made explicit his views, and the teacher is now more aware of the nature of the incorrect conceptions. Hopefuly the teacher will be able to provide critical experiences for the student to challenge the status of the views presently held by him. He must also be ready and prepared to offer extended opportunities for the student to experience the usefulness of the scientific perspectives. I believe that we shall have succeeded even if we only convince the student that part of the scientific enterprise is about searching for more plausible models by consensus; that if he can come up with a successful explanatory model, good luck.

This technique seems to have been very successful and most subjects are happy with it; but only time can tell. The awareness phase of this strategy as outlined above in most cases may include the other phases mentioned by Pines and West [1986]. This paper also suggests that teachers should spend a substantial portion of their time diagnosing student thinking errors, and in identifying moves the students use to ignore the inconsistencies, avoid dissonance and resist conceptual change.

Briefly, the disequilibrating phase involves the introduction of anomalies that challenge the existing belief system. The reformation phase involves the presentation of formal concepts that lead to the resolution of the anomalies and the dissipation of the cognitive dissonance so ingeniously engineered by the teacher [Pines and West 1986].

My experience has been that it is possible to work at all these levels in any single class discussion. This comes out clearly in the one session which I have discussed above. The disadvantage is that of time. Each session may take more than an hour and usually indicates that more interviews are needed.

I rate this approach very highly in my strategies. I strongly believe, as I have indicated before, that students' inappropriate conceptions when they have been diagnosed must be addressed directly there and then and set into proper perspectives. This is a very powerful and effective method of tackling alternative conceptions.

6.4.0 Summary:

These concept re-inforcement and remedial strategies have made for remarkable interest among students. They have been used to supplement conventional classroom teaching activities. As an exercise they have been of great benefit to the lecturer because he becomes more aware of the immensity of the problem. Once the lecturer has a general picture it is possible to integrate demonstrations of experiments into classroom teaching in order to tackle the more general inappropriate concepts even at this level.

6.5.0 Conclusion

In this research effort it became clear that students who enter first year university classes have many conceptual problems regarding direct current electricity. The alternate conceptions are largely related to confusion in the understanding of "electricity" as current or as energy; that whatever this is, it originates from the source (cell) and flows mechanistically to resistors and makes lamps light, appliances hot etc;. The ideas are not based on an understanding of the concepts of energy, and potential (energy) difference as such, because the students consider the electric circuit as a current system. The association with emf, p.d etc; may be there, but it is really artificial and is a rule of thumb by way of the Ohm's law V=IR.

Most students basically do not use an energy framework. A fundamental outlook is that electricity (whatever it is) is "used" (and dissipates) and there is less of it flowing on the other side of the resistor or lamp etc. "Used" in the common sense meaning of the word, in that there was electricity flowing in the conductor and now it is not there and instead light and heat etc; have come out. The average student in my classes relates only superficially to the idea that light, heat are in fact energy. In his mind these are really other things since energy is fundamentally kinetic. So even at this level of looking at it, the concept of conservation is not reinforced at all when electric current (=energy?) disappears and light (say) appears in its place.

The inadequacies in conceptualisation and tendencies in interpretation of d c electricity phenomena displayed by the students were common place and universal. The majority of the students are affected. My findings compare favourably with those of other research workers in this field (Duit and Jung 1984). Whilst I make this point, I must also hasten to submit that I think that there was a significant factor in the conceptualisation of my students largely rooted in the way of life, the fundamental philosophies of this, and the environment from which the students came.

I have discussed some of these implications.

For example: There was a tendency to be affected by the cause-effect structure of the English language as they perceived it, and as a result to think locally and not globally about features of the electric circuit. Quite often some would fall back on indigenous language equivalents of names like energy, force, current etc;.

Light was not perceived as energy, but just a sensation. They believed their teachers more that understood them; i.e, accepted 'explanations' of concepts gullibly without feeling the need to reason things out. There was no reason to make collective sense of natural phenomena, no pressing need that nature behave in predictable fashion. This tendency may have arisen from the lack of life-world experience and exposure to the ways of modern technology and society. It could also have come out as being characteristic because of the lack exposure to controlled experiences in the school situation related to what had to be studied and understood. I found that language and metaphor played a significant role; that verbal comprehension is a very important variable in the cognitive process. The additional problem here for African students is that they learn in a second language, English, and through media which do not have a sensitivity for the vernacular language.

To my mind, the research has raised some inferences for physics instruction especially at the schools level. I am more convinced than ever before that student intuitive belief systems and alternative conceptions have a bearing on teaching; that these can provide guidelines for the analysis of the nature and sequencing of instruction. Research could be undertaken in order to determine which elements of the instructional system, which additional strategies, enhance meaningful learning. There is already consensus that we need to design curricula which build on, rather than ignore, those students' views and acknowledged inappropriate views which have been identified by research [Fredette 1981; McLelland 1984; Osborne et al 1983; Pines and West 1986; Johsua and Dupin 1987 etc]. For example, we need to extend students' conceptions toward the non personalised and more abstract view of science. Secondly, there is a need to determine the best way to organise and present the difficult and often abstract concepts involved in

Physics [French 1988]. Most expects agree that the organisation of any knowledge taught is no less important than its content [Karplus 1981; Preece 1983; Reif 1981; French 1988]. Thus teachers must pay careful attention that knowledge is presented in an effectively organised form; for example, emphasis could be given to certain pivotal concepts like energy.

As a direction for further research it seems that it would be profitable to investigate, using the techniques of constructivism, the cognitive structures of the body of students at the local level, and to establish what proportion of those entering university physics courses are able to understand the prerequisite physical concepts. One would like to see more broad based investigations of alternative conceptions at the high school and university level catalogued, especially in the areas of mechanics and electricity. This would enable the drawing of more meaningful comparisions with studies elsewhere in the world, thus making it possible for alternative conceptions research in Southern Africa to benefit from that research. Further research could lead to a clearer distinction between inappropriate conceptions which result from the natural environment of the child and those that come from the school background ie. teachers and textbooks. The research might be able to arrive at more specific conclusions on the nature of teacher - student interactions (and textbooks separately), and how these may influence the cognitive development of students.

Additional investigations into the spontaneous explanations of students could lead to findings on how children reason, the analogies they make as they try to derive meaningful conclusions from instruction, data and other observations. This would bring research nearer to uncovering any patterns used in building frameworks of scientific concepts, or confirm if students do in fact build scientific frameworks as such and construct knowledge. Student naive theories could be classified in terms of whether they are incorrect and nonsensical or simply just inadequate in their explanatory powers. Thus the perceptions of students on the role of models could be further enriched by using some of their models and extending the explanatory powers of these to acceptable levels.

There is a need to determine which in the end are significant parameters for measuring achievement and success in the scientific enterprise. Some techniques in inappropriate conceptions research rely too heavily on finding out if students succeed in regular content tests. A complicating factor is that other techniques in the research have produced reports which indicate that a significant fraction of students who are successful in physics do not often try to understand physics concepts [Peters 1982; Thornton 1987]. Diagnostic tests should be made to test fundamental conceptions and not mere recall of facts. These students operate at a minimum to get by, and make use oversimplified rules and localised strategies. They rarely look for a consistent interpretation across all possible phenomena, and for coherence in the theory. Most perform well whilst they do not seek understanding but adopt strategies and techniques in encyclopaedic fashion, for survival and to pass examinations. Some researchers have come to accept that traditional forms of assessment do not often probe for understanding [Gunstone 1987], and this does not help. In addition some authors have pointed out examples of students using physics analysis to solve a problem in a physics context whilst interpreting the same phenomenon in everday life via a different belief system [Champagne et al 1980; Gunstone 1987; Osborne et al 1983; Thornton 1987].

There is ample evidence in the study that student thinking is at a formative stage, is basically localised and haphazard, and lacking in fundamental conceptual frameworks. Bearing this in mind, there is merit in the debate that is going on as to whether the vast majority of students do in fact have established conceptual frameworks as such at the high school stage, or whether their intuitive ideas / alternative conceptions are in fact not intelligently learned from, but are triggered by experience [Preece 1984]. I submit though that we have to accept that if these inappropriate frameworks persist beyond the school years, into university years, and become established as ingrained, they have to be treated as alternative frameworks. Perez [1985] advances the view that the resemblance between the children's framework on mechanics and the Aristotelian paradigm is not accidental, but is the result of the same methodology, the methodology of superficiality.

We have to accept the implications for science; namely that, whatever these frameworks are, they have to be accommodated. The instructional system has to make efforts to change, reinforce, consolidate the apparently nebulous separate concepts and to merge them into a coherent theory which is acceptable physics.

Although it seems that physics is conceptually difficult to most students, a redeeming factor is that the majority of our students are excited by it, and are enthusiastic. At this stage we have not had to be anxious about declining enrolments. This is a good sign.

APPENDIX

Includes:

(i) Questionnaires used in the preliminary investigations
(ii) Diagrams of electric circuits used in the personal interviews

UNIVERSITY OF FORT HARE
DEPARTMENT OF PHYSICS

PHYSICS QUESTIONNAIRE

NAME :

You may respond to this questionnaire anonymously; the data obtained from it will be used for research purposes, not for class records.
Use the answer sheet provided to answer the questions in this sheet.

With each question four possible answers are supplied, only ONE of which can be correct [unless you are told otherwise]. Choose the one which you think is the correct response, and mark the corresponding box on the answer sheet with a cross thus: [X]

If you do not know enough about the subject, mark the box 5 with a cross for the question concerned.

A. In general do you enjoy studying and being at a University or do you regard it as just another form of work.

1. Very enjoyable. ☐
2. Moderately enjoyable. ☐
3. Is alright but it is just another form of work. ☐
4. Actively dislike. ☐
5. ☐

B. Have you found physics this year [or physical science in general]

1. Very interesting. ☐
2. Moderately interesting. ☐
3. Alright but it is just a form of work. ☐
4. Boring. ☐
5. ☐

C. Reasons for lack of interest or lack of achievement [or source of difficulty] are:
You can cross more than one but not more than FIVE choices here.

1. Have not adjusted to life at the university as yet ☐
2. Lectures were/ are poor. ☐
3. Physics [or physical science] is just not a subject that interests you ☐
4. Too much to cover in short time ☐
5. Unable to concentrate on the aspects that I enyoy ☐
6. Too mathematical, not enough physical understanding ☐
7. Too much formulae, more applications needed to relate to reality. ☐
8. Too many things have to be believed or accepted without really understanding them. ☐
9. Inadequate preparation from High school. ☐

OTHER REASON :.. .. ..

D. Do you have a problem understanding what is really meant by certain words, ideas, concepts used in physics? For example : force, average velocity, vector, gravity, work, or relationships: Energy = Heat, energy = work, Kinetic and Potential Energy, Difference between energy and power etc. Newton's 3rd law or any other.

1. Definitely Yes ☐
2. Sometimes ☐
3. maybe - but I am not aware ☐
4. No definitely ☐
5. ☐

If so please list some, of the concepts in which you have difficulties; where possible explain briefly.

.. ..
.. ..
.. ..

E. Do you solve physics problems on your own

1. Often. ☐
2. Occasionally ☐
3. Rarely - Almost never. ☐
4. Never. ☐
5. ☐

F. Have you decided to continue with the study of physics because

1. You find Physics to be an interesting subject. ☐
2. You think that it offers good employment and salary opportunities. ☐
3. You think that it offers a useful career regardless of salary etc. ☐
4. You just need another subject [physics] as part of your degree. ☐
5. ☐

G. Do you think that physics helps you in any way to understand the physical world [life] around you better?

1. Definitely Yes ☐
2. Maybe - but only slightly ☐
3. No. ☐
4. ☐
5. I do not know ☐

H. If physics is divided broadly into the following sections

A. Mechanics [deals with particles, their motion and displacement, velocities, acceleration, energy, Newton's laws etc.] ☐
B. Heat ☐
C. Light and optics. ☐
D. Electricity and magnetism ☐
E. Atomic and nuclear physics ☐

I. The section/s in which you are comfortable is/are [more than one choice allowed]

1. ☐
2. ☐
3. ☐
4. ☐
5. ☐

Any other more specific section you really like

.. ..

.. ..

The section/s in which you have found most difficulty is/are [more than one choice is allowed]

1. ☐
2. ☐
3. ☐
4. ☐
5. ☐

Any other more specific problem area in physics ... ...

.. ..

....

J. Which of the Matric work do you think your teacher did not do enough of

1. Because of Shortage of time ☐

.. ..

OR

2. Because he was not familiar with them ☐

.. ..

Did you have enough practice or have you had adequate experience in working with electricity or electrical instruments [e.g. lights. batteries, toys, gadgets, appliances etc.]

K. As a Hobby

1. Yes ☐
2. Maybe ☐
3. Definitely No ☐

M. At Home.

1. Yes ☐
2. Maybe ☐
3. Definitely No ☐

N. Do you feel that you have done a good amount of practical work in physical science at school

1. A lot of practical work was done ☐
2. Rarely - Almost never ☐
3. Never ☐

O. Time spent by you doing practical work at school

1. 30 minutes a week ☐
2. 60 minutes a week ☐
3. 90 minutes a week ☐
4. 2 hour and more ☐
5. .. .. ☐

Number of students in the practical group: .. .. ..

P. Do you think that doing practical work has helped improve your understanding of physics or physical science

1. Has helped a great deal. ☐
2. Has not helped much. ☐
3. Has in fact confused the physics theory. ☐
4. Has definitely not helped - practical is boring. ☐
5. ☐

Q. Do you like reading science fiction?

1. Yes ☐
2. Sometimes ☐
3. I find it boring ☐
4. .. ..
5. ☐

R. Are you confident that if you work fairly and reasonably diligently you will pass this course in physics at the end of the year.

1. Definitely ☐
2. Maybe - [what is your problem? write reason below] ☐
3. No [what is your problem? write reason below] ☐

REASON : .. ..

.. ..

UNIVERSITY OF FORT HARE

DEPARTMENT OF PHYSICS

PHYSICS 1 DIAGNOSTIC TEST OF PRIOR KNOWLEDGE

You may write this test anonymously; the information from it will be used for research purposes, and not for class records.

Use the answer sheet provided separately to answer the questions in this test.

With each question four possible anwers are supplied, only ONE of which is correct. Choose the one which you think is correct, and mark the corresponding letter on the answer sheet with a cross thus:

A. ~~B~~ C. D. E. [Here B is marked as the correct answer]

If you do not think that you know enough about the subject to answer a particular question, mark the letter E for the question concerned

---

1. As a mass m falls freely from A to B due to gravity, the total mechanical energy [excluding air resistance] of the mass will
   A. be doubled
   B. remain the same
   C. decrease
   D. we cannot decide because not enough information is given e.g. the value of the mass and the velocity v at the point B
   E.

2 The sum of all the forces acting on a body is equal to zero when the body is
   A. travelling in a circle at a constant speed
   B. falling down freely under gravity
   C. moving in a straight line with constant velocity along a horizontal plane.
   D. Moving with a constant acceleration along a horizontal line
   E.

3. A particle moves along a circular path at a constant speed v. The acceleration of this particle
   A. is zero
   B is constant and is directed towards the centre of the circle
   C. is constant and is directed away
   D. is not constant but changes in magnitude and direction as the particle moves
   E.

4. The potential of an object near the Earth is equal to m g h and its magnitude
   A. is inversely proportional to the distance from the ground
   B. is directly proportional to the distance from the ground
   C. is inversely proportional to the square of the distance from the ground.
   D. is not dependent on i ts distance from the ground.
   E.

5. If a rocket moves directly upwards at a constant speed, then as it moves up its kinetic energy is
   A. decreased by more than its potential energy is increased
   B. decreased by the same amount as its potential energy is increased
   C. equal to zero
   D. unchanged but has a definite value
   E.

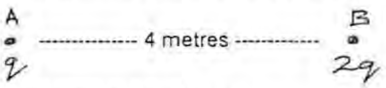
6. Gravitational and electrostatic [coulomb forces] are similar in some respect but different in others. Which statement is Not true for both gravitational and electrostatic force.
The force exerted by one particle [of mass m or charge q] on another
A. varies as the inverse square of the distance between the particles
B. Depends upon the mass or charge on each particle
C. Can be both a repulsive force and an attractive force
D. Can be demonstrated experimentally
E.

7. The force of attraction between two charges can be doubled by
A. Halving the distance betwen them
B. Doubling the distance between them
C. Doubling the charge on both objects.
D. Doubling the charge on one of the objects.
E.

Given : $F = \frac{k q_1 q_2}{r^2}$

8. Two identical conducting spheres A and B with charges of (A) + 4 units of charge and (B) + 6 units of charge are brought into contact and then separated.
What will be the charge on sphere A after they have been separated?
A. Zero ?
B. + 5 units
C. + 10 units
D. + 4 units
E.

9. Two spheres A and B have charges on them



as shown in the diagram.
How does the magnitude of the force exerted by A on B compare with the magnitude of the force exerted by B on A ?
A. four times the force on B
B. two times the force on B
C. the same as the force on B
D. half the force on B
E.

10. Two uncharged conducting spheres are suspended by nylon threads and touch each other. With a positively charged rod held near sphere 1 the two spheres are separated.
The charges on the two spheres will be

	Sphere 1	Sphere 2
A.	none	positive
B.	negative	positive
C.	none	none
D.	negative	none
E.		

11. Which of the following are vector quantities [more than one choice is possible here]
A. Electric charge
B. Electric potential
C. Electric field intensity
D. Kinetic Energy

12. Which one of the following would be the correct unit for energy per unit time?
    A. Ampere
    B. Volt
    C. Watt
    D. Joule
    E.

13. A coulomb is a unit of
    A. Resistance
    B. Power
    C. Current
    D. Charge
    E.

14. Which of the following would be the correct unit for energy per unit charge
    A. Ampere
    B. Volt
    C. watt
    D. Joule
    E.

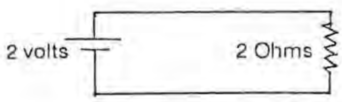
15. At a given point the direction of the electric field is towards the north.
    The force exerted by the field on a proton placed at this point is towards the
    A. North
    B. South
    C. West
    D. does not have a definite direction
    E.

16. How long must a 100 watt light operate to dissipate [or use] 1 000 Joules of energy?
    A. 100 000 seconds
    B. 1 100 seconds
    C. 900 seconds
    D. 10 seconds
    E.

17. A 30 Ohm and a 60 Ohm resistor are connected in series to a battery. Compared to the rate at which heat is is produced in the 30 Ohm resistor; the rate at which heat is produced in the 60 Ohm resistor is
    A. the same as that produced in the 30 Ohm resistor
    B. twice as much . . ..
    C. half that produced in the 30 ohm resistor
    D. is zero like that produced in the 30 Ohm resistor
    E.

    Given: $H = I^2 R t$

18.



How many coulombs of charge will pass through the 2 Ohms resistor in one minute?
    A. 1
    B. 60
    C. zero
    D. 4
    E.

19. A certain student wrote :

"Since $R = V/I$ is the resistance of a conductor expressed in ohms where V = the p.d. across it in Volts and I = current through it expressed in Amperes, we may deduce that the resistance of a conductor increases as the p.d. across the conductor; and vice versa"

A. This is correct

B. The equation is faulty since the term V/I should be I/V

C. The statement is faulty since the phrase

"increases as the p.d. across .. .. " should be " decreases as the p.d. across .. ."

D. The logic of the statement is faulty since V and I do not change independently of each other.

E.

20. The resistance of a given fixed length of a metal wire of circular cross section is R.

A second wire is made of the same material same length but with a diameter two times that of the original wire.

The resistance of the second wire is

A. 4R

B. R/2

C. 2R

D. R/4

E.

Given :

$$R = p \frac{\text{length}}{\text{Area of X-section}}$$

21. A current of 3 Amperes is maintained in a conductor with a potential difference of 120 volts across it.

The power supplied to the conductor is

A. 0,025 Watts

B. 40 Watts

C. 360 Watts

D. 1 080 Watts

E.

University of Fort Hare

Department of Physics

SCCO. QUESTIONNAIRE

The questions asked in this questionnaire will be used as part of a research programme and are not for the purpose of a class test. They may be answered anonymously or by use of a pseudonym.

NAME :

There are four possible answers to each of the questions asked. Please respond to each question by marking with a cross the box corresponding to the response which to you seems to be the most suitable one.

X

If you do not think that you know enough about the subject to answer a particular question, mark the box corresponding to (v), for the question concerned.

1. The two appliances in Figure A are wired to the mains [electricity source] in parallel so that they may have the same
   (i) current in them ☐
   (ii) operating temperature ☐
   (iii) power supplied to them ☐
   (iv) voltage across them ☐
   (v) ☐

2. Compare the three circuits in Fig: B C; and D;
   How would you expect the brightness of the lamp in Fig C to be?
   (i) the same as that in D ☐
   (ii) brighter than that in D ☐
   (iii) the same as that in Fig. B ☐
   (iv) brighter than that in Fig. B ☐
   (v) ☐

3. In Fig E a student wishes to bridge the the gap between X and Y so that the bulb may glow as brightly as possible. He should use
   (i) a short thick conductor ☐
   (ii) a short thin conductor ☐
   (iii) a long thick conductor ☐
   (iv) a long thin conductor ☐
   (v) ☐

4. In Fig F a filament lamp [bulb] is shown. The filament of the bulb becomes white hot because
   (i) the wire is wound into a coil ☐
   (ii) the wire is thinner than the lead wires ☐
   (iii) the wire is shorter than the lead wires ☐
   (iv) the wire carries a higher current than the lead wires ☐
   (v) ☐

5. The voltage [potential difference] across the bulb in Fig G [with switch open] is
   (i) equal to that across the bulb in Fig H [switch closed] ☐
   (ii) equal to zero since there is no current ☐
   (iii) is approximately equal to the e.m.f. of the battery since the internal resistance of the battery is very small ☐ ☐
   (iv) it will be greater than the e.m.f. of the battery ☐
   (v) ☐

6. The potential difference across the lamp 1 in Fig. I
   - (i) will be equal to that of the lamp 1 in Fig. H ☐
   - (ii) will be less than that of the lamp 1 in Fig H ☐
   - (iii) will be equal to that of lamps 1 and 2 in Fig. J ☐
   - (iv) will be equal to that across lamp 1 in Fig. J ☐
   - (v) ☐

7. In passing through a lamp in a closed circuit [Fig. J] a charged particle ['carrier' of current] moving in the direction of the current
   - (i) gains some energy ☐
   - (ii) loses some energy ☐
   - (iii) gains some energy and loses some energy ☐
   - (iv) neither gains nor loses energy ☐
   - (v) ☐

8. In passing through the battery Fig. F [internal resistance zero] a charged particle ['carrier' of current]
   - (i) gains some energy ☐
   - (ii) loses some energy ☐
   - (iii) gains some energy and loses some energy ☐
   - (iv) neither gains nor loses energy ☑
   - (v) ☐

9. In the circuit in Fig. J the electrical potential energy at a point
   - (i) is lower than the electrical potential energy at point b ☐
   - (ii) is equal to the electrical potential energy at point b ☐
   - (iii) is greater than the electrical potential energy at point b ☐
   - (iv) is equal to zero ☐
   - (v) ☐

10. In Fig. I, given that the internal resistance of the battery has a fixed value reasonably large, the p.d. across lamp 1
   - (i) is definitely equal to the e.m.f. of the battery ☐
   - (ii) is less than the e.m.f. of the battery ☐
   - (iii) is equal to zero ☐
   - (iv) is greater than the e.m.f. of the battery ☐
   - (v) ☐

11. A piece of copper made into a thin wire is connected in series in Fig. K as shown. The same wire is re-moulded so that it is now thicker and much shorter and is connected to the same circuit [as in Fig. L]. The resistance of the wire in Fig. L
   - (i) is greater than that of the wire in Fig. K ☐
   - (ii) is less than that of the wire in Fig. K ☐
   - (iii) is equal to that of the wire in Fig. K ☐
   - (v) ☐

12. In Fig. M and in Fig. N the potential difference [V_{ac}] across lamp 2 is
   - (i) equal to the potential difference across lamp 1 [V_{ab}] ☐
   - (ii) is equal to the potential difference across the lamp in Fig. N ☐
   - (iii) is equal to V_{abc} [the potential difference across lamps 1 and 3 in Fig. M] ☐
   - (iv) is definitely less than the p.d. across lamp in Fig. N ☐
   - (v) I do not know ☐

13. Please mention below any problems that you find in understanding the meanings of certain ideas, concepts, words in studying electricity or the related subject area

.. ..

.. ..

[Adapted from Johnstone and Mughol 1978]

Fig. A

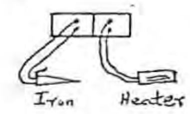


Fig. B

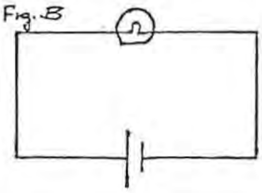


Fig. C

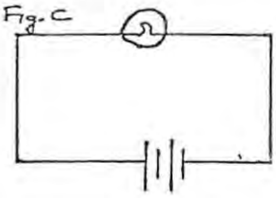


Fig. D

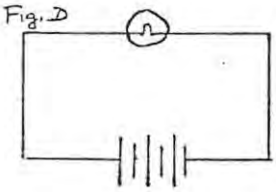


Fig. E

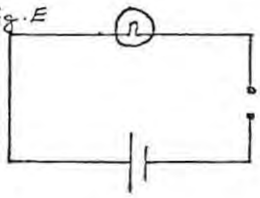


Fig. F

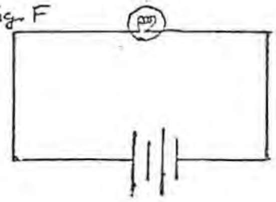


Fig. G

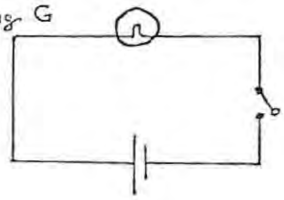


Fig. H

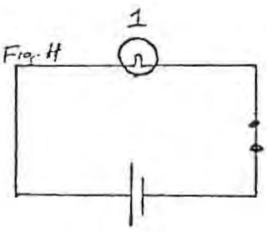


Fig. I

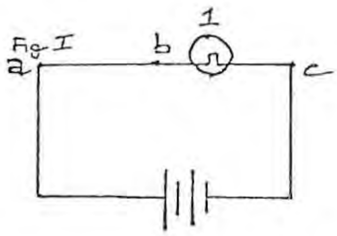


Fig. J

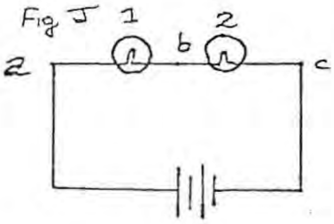


Fig. K

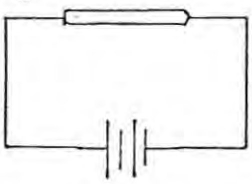


Fig. L

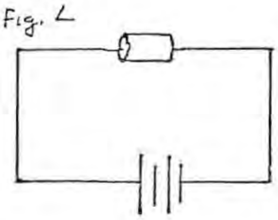


Fig. M

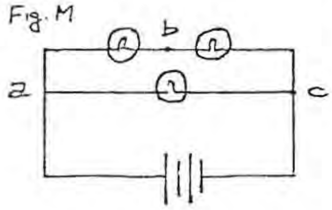
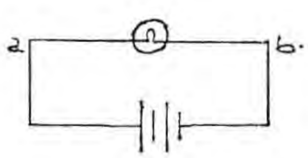


Fig. N



University of Fort Hare

Department of Physics

This question should be answered on the question paper.
Each of the questions or incomplete statements below is followed by Five suggested answers or completions.
Select the one that best answers the question or completes the statement; write the symbol which corresponds to the option in the box for the particular question.

Example : eZola is a residence for

1. Male students
2. Female students [2]
3. Both male and Female students

where 2 is the correct answer or option

A. The acceleration of a freely falling body is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

B. The velocity of a freely falling body is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

C. The force acting on a freely falling body is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

D. If a body is moving along a straight line, traversing equal distances at equal times, the force acting on the object is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

E. The velocity of a car moving with an acceleration of 11 metres per second ^{2} is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

F. If any object is moving in a given direction at a constant velocity and there is no friction or air resistance, the force acting on it is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

G. If the velocity of the object in F is increasing at a constant rate, the acceleration is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. decreasing at a constant rate

H. If the velocity of the body in F is increasing at a constant rate, the force is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

I. If the acceleration of the object referred to in F is increasing at a constant rate, the force is :

1. Zero
2. Constant but not zero
3. Increasing at a constant rate ☐
4. Decreasing at a constant rate

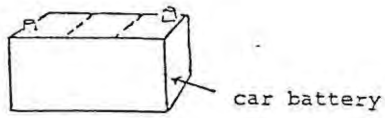


Figure 1(a)

Is there electric current in the battery?

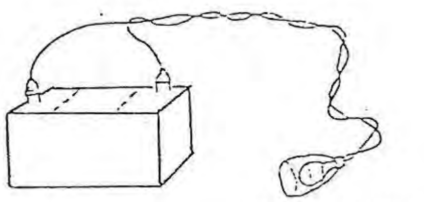


Figure 1(b)

Is there electric current in the battery now?

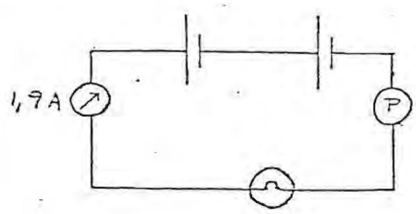


Figure 2(a)

The current shown by some ammeters is given
What is the current shown by the other ammeters?

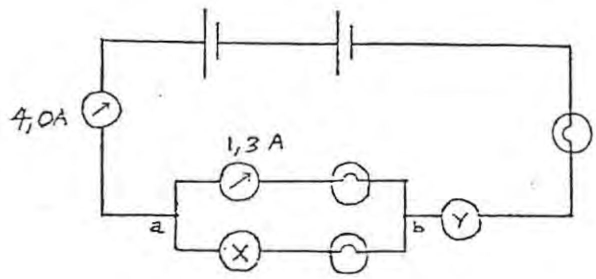


Figure 2(b)

What is the current shown by the other ammeters, X and Y?

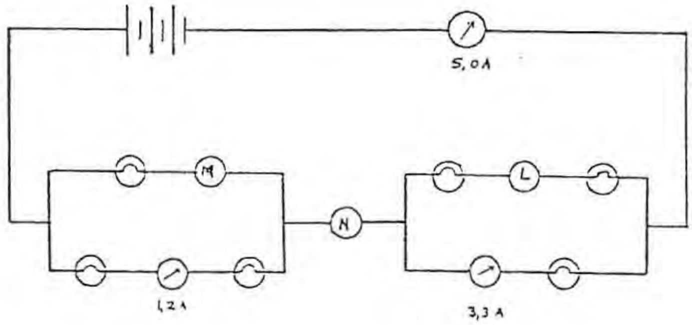


Figure 2(c)

What is the current shown by the other ammeters?

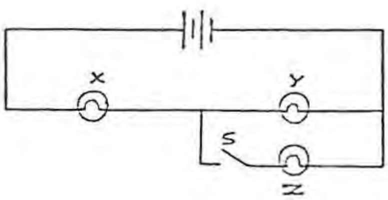


Figure 3

The bulbs X, Y and Z are identical
When switch S is closed bulb Y will become brighter
Is this statement True or False? Why?

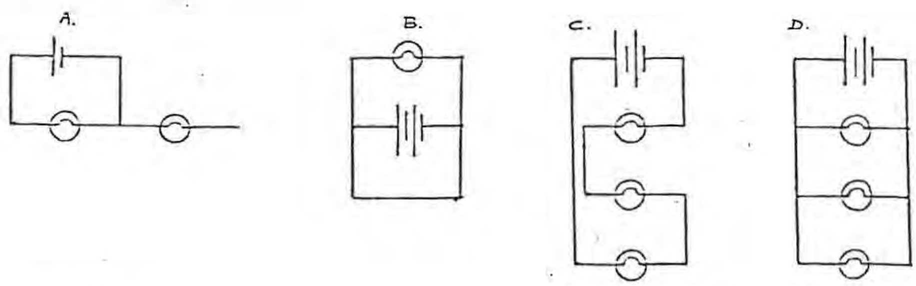


Figure 4

In which circuits are the bulbs in series?
In which circuits are the bulbs in parallel?
In which circuits are the bulbs or bulb brightest?

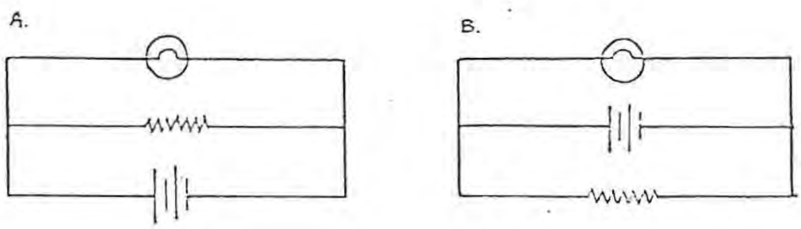


Figure 5

Are these two circuits similar?
Compare the current in the bulb in (a) and in (b)

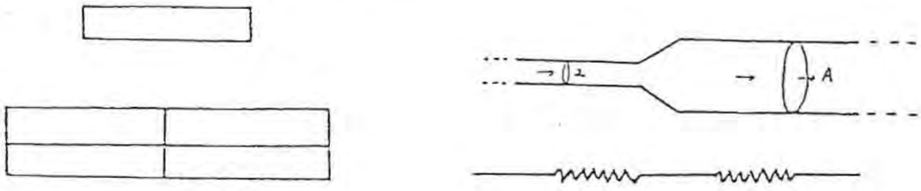


Figure 6

Metal strip P has a resistance between its ends of 6 ohms
Strip Q is twice as wide and twice as long as the first strip
The resistance of strip Q will be
A. 3 B. 6 C. 12 D. 24

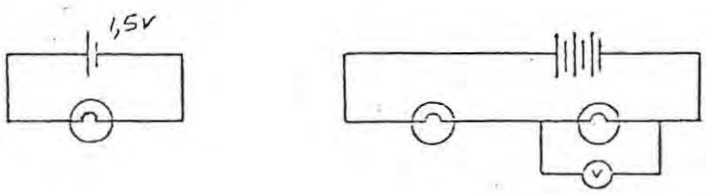


Figure 7(a)

In Fig 7(a) (i) the voltmeter reads 1,5 v
The circuit in Fig 7(a) (ii) contains three such cells and two similar bulbs. Assuming that the cells have no internal resistance the reading (in volts) on the voltmeter in Fig 7(a) (ii) will be

A. Zero B. 1,5 C. 2,25 D. 4,5

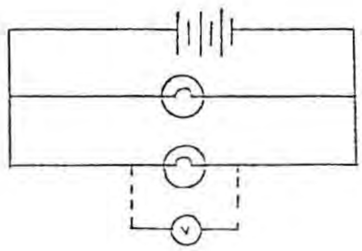


Figure 7(b)

The cells and bulbs shown in Fig 7(b) are similar to those in Fig 7(a)
The readings (in volts) on this voltmeter will be

A. Zero B. 1,5 C. 2,25 D. 4,5

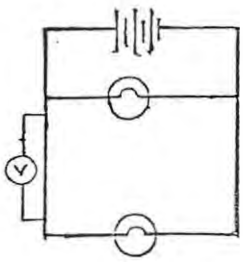


Figure 7(c)

The circuit in Fig 7(c) also contains the same type of cells and bulbs used in 7(a)
The reading on this voltmeter (in volts) will be

A. Zero B. 1,5 C. 2,25 D. 4,5

List of references

Allen, R D 1981: Intellectual development and the understanding of science etc:
J of College Teaching Nov 1981 94

Allie, S and King, J E 1987: Simple electrical circuits: A Practical tutorial approach
Paper at S.A Institute of Physics Conference univ of Natal: Jul 1987

Arons, A B 1976: Cultivating the capacity for formal reasoning ..
Am J Phys 44 (9) 834
1979: Cognitive level of college physics students
Am J Phys 47 (7) 650
1982: Phenomenology and logical reasoning in introductory course
Am J Phys 50 (1)

Archenhold et al [Ed] 1980 :Cognitive Development-Research in science and mathematics
Proceedings of International Seminar University of Leeds,

Ausubel, D P 1968 :Educational Psychology: A cognitive view: Holt Rinehart New York

Bady, R 1978: Methodological issues in formal operations research:
What does it mean to be formal? Science Education 62 (2) 233

Barnes, G 1977: Students' scores on Piaget-type questionnares versus semester grades
for lower division College students
Am J Phys 45 (9) 841

Barnes, G and Barnes, G B 1980: Students' scores on Piaget-type questionnaires before
and after taking two semesters college physics
Am J Phys 48 (9) 774

Bueche, R 1977: Physics for Scientists and Engineers: Mc Grawhill New York

Bullock, B 1979: The use of models to teach elementary physics
Phys Educ 14 312

Calliot, M 1983: "Problem solving in electricity": Paper delivered at:
Annual Meeting of the American Educ Research Assc'n Montreal Canada

Cantu, L L and Dudley, J D 1978: Concrete and formal Piagetian stages and
science concept attainment: J Res in Sc Teach 15 (2) 135

Champagne, Klopfer and Anderson 1980: Factors influencing learning of classical mechanics
Am J Phys 48 (12) 1074
1981 :Science Educ 65 (5) 493

Champagne, Klopfer and Gunstone, 1982: Cognitive research and the design of
science instruction: Educational Psychologist 17 (1) 31

Champagne, A B and Klopfer, L 1983: Naive learning and Science Learning:
Paper presented annual meeting AAPT

Chiapetta, E L 1976: A review of Piagetian studies relevant to science instruction at
the secondary and college level": Science Education 60 (2) 253

Cleare, C C 1983: In Helm, H and Novak, J 1983 Proceedings of International Seminar on:
:Misconceptions in science and mathematics Cornell Univ Dept of Educ Ithaca.N Y

Clement, J 1982: Student's preconceptions in introductory mechanics
Am J Phys 50 (1) 66

Cohen, H; Hillman, D and Agne, R 1978: Cognitive level and college physics and achievement
Am J Phys 46 (10) 1026

Cohen, R ; Eylon, B & Ganiel, U 1983: Potential difference and current in simple electrical circuits: A study of student's concepts
Am J of Phys 51 (5)

Davis, A D 1980: The case for Sophomore Mechanics. Am J Phys 48(9) 778

Decarcer, et al 1978: Implications of Piagetian Research for High School teaching : a review of literature Science Educ 62(4) 571

Driver, R., and Easely, J 1978: Pupils and paradigms Studies in Science Educ 5 61

Driver, R 1982: Children's learning in Science Educational Analysis 4 (2) 69

Driver, R and Erickson, G 1983: Theories in Action: Some Theoretical and Empirical Issues in the Study of students' Conceptual Frameworks in science
Stud in Science Educ 10 37

Driver, R., 1983: The Pupil as a Scientist: Milton Keyes: Open University

Duckworth, E 1964: Piaget rediscovered: J of Res in Sc Teach (2) 172

Duit, R 1984: Learning about energy at school: Phys Educ 19 59-66
1983: Energy conceptions held by students and the consequences for teaching:
In Helm, H and Novak, J [Eds;] Proceedings of International Seminar:
Misconceptions in science and mathematics Cornell University Ithaca June 1983

Duit, R., Jung, W., Rhoneck, C.,(Eds.) 1984: "Understanding electricity--":Proceedings of International Workshop: Pedagogische Hochschule Ludwigsburg, Germany

Einstein, A., and Infield, L 1938: The Evolution of Physics: Cambridge University Press

Erickson, G L 1980: Children's viewpoint of heat: a second look
Sc Educ 64 323

Evans, J 1978: Teaching electricity with batteries and bulbs
Phys Teacher 16 (15)

Falk, G., Herrmann, J and Bruno, G 1983: Energy forms or energy carriers
Am J Phys 51(12) 1074

Feher, E 1983: Identification of certain preconcepts that hinder science learning: Examples involving electricity:
In Helm, H and Novak, J [Eds;] Proceedings of International Seminar:
Misconceptions in science and mathematics Cornell University Ithaca June 1983

Fensham, P J: A research for new objectives in science teaching
1983 Sc Educ 67 (1) 3

Fredette, N H 1981: College students' conceptions of electric circuits
Dissertation.Abstracts International 42(3)1085-A

Fredette, N H and Lochhead, J 1980: Students' conceptions of simple circuits
Physics Teacher March 194

French, A P 1988: Some thoughts on introductory physics courses
Am J Phys 56 (2)

Gardner, R 1980: What does a voltmeter do?: Physics Teacher April 1980 230

Gilbert, J, Osborne, R and Fensham, P 1982: Children's science and its consequences for teaching: Science Education 66 (4) 623

Gilbert, J & Watts, D 1983: Concepts, misconceptions and alternative conceptions: Changing perspectives in science education : Stud in Science Educ 10 61

Griffith, W T 1985: Factors affecting performance in introductory physics courses
Am J Phys 53 (9) 839

Gunstone, R F 1987: Students' understanding in Mechanics: Am J Phys 55 (8)

Gunstone, R. F. and White, R 1981: Understanding gravity : Science Educ 65 291

Halloun, I. A. and Hestenes, D 1985: The initial knowledge state of college physics students
Am J Phys 53 (11) 1043
:Common sense concepts about motion Am J Phys 53 (11) 1056

Hartel, H 1982: The electric circuit as a system: Eur J of Sc Ed 4 (1).1 45

Heald, M A 1984: Electric fields and charges in elementary circuits
Am J Phys 52(6)

Helm, H 1970: Unpublished PhD thesis: Rhodes University
1978: Misconceptions about physical concepts amongst S. A. pupils studying Physical Science: S A Journal of Science 74 285
1980: Misconceptions in physics amongst S A students
Physics Education 15 92
1981: Conceptual misunderstandings in Physics
Perspectives 3: University of Exeter, School of Educ
1985: "A problem oriented approach ":Paper presented Annual meeting of Amer Educ Research Ass Chicago

Helm, H and Gilbert, J 1985: Thought experiments and physics education: 1&2
Phys Educ 20 124 and 211

Helm, H, and Novak, J (Eds.) 1983: In Proceedings International Seminar:
Misconceptions in science and mathematics: Cornell Univ. Ithaca, N.Y. 1983

Hewson, P 1982: Seminar on Misconceptions in physical science
University of Cape Town June

Hewson, P 1985: Diagnosis and remediation of an alternative concept of velocity using a microcomputer program: Am J Phys 53 (7) 1985 684

Hewson, M. G., and Hewson, P., 1981: Effect of instruction on prior knowledge and conceptual change strategies on science learning:
Paper presented at NARST Apr 1981

Hewson, P 1985: Epistemological commitments in the learning of Science:
Examples from dynamics: Eur J of Sc Educ: vol 7(2) 163

Horsfield, E 1984: Aspects of scientific method in the natural sciences
Am J Phys 52(9) 809

Hudson, H T and Mc Intire, 1977: Correlation between mathematical skills and success in physics :Am J Phys 45 (5) 470

Hudson, H T and Rottman, R 1980: Mathematics ability of beginning physics students:
Phys Teacher April 1980 305

Iona, M 1979: Teaching electrical resistance: Physics Teach vol 17 May 1979 299
1984: Multiple choice questions : Am J Phys 52 (5) 1984

Ivowi, U M V 1983: Misconceptions in physics among Nigerian students In:
In Proceedings International Seminar:
Misconceptions in science and mathematics: Cornell Univ. Ithaca, N.Y. 1983

Johnstone, A and Cassels, J 1978: "What's in a word": New Scientist May 18

Johnstone, A H and Mughol, A 1978: The concept of electrical resistance
Phys Educ 13 1978 46

Johsua, S 1984: Students' interpretation of simple electrical diagrams
Eur J of Sc Educ Vol 6 (3) 271

Johsua, S and Dupin, J 1987: Taking into Account Students' Conceptions in Instructional Strategies: Cognition and Instruction 4(2) 117

Jones, H and Mooney, R 1981: An approach to conceptual difficulties in physics
Phys Teacher vol 16 356

Karplus, R 1981: Educational aspects of the structure of Physics
Am J Phys 49(3) 238

Karrqvist, C 1985: The development of concepts by means of dialogue centred on experiments:
In Duit, R et al [Eds;] 1984: "Aspects of Understanding Electricity" p215 [Kiel,IPN]

Klein, C 1982: Children's concept of the earth and sun
Science Educ 65(1) 1982 95

Klopfer, L E [Ed;] 1983: Science Education: Summary of Research Vol 67 (3) 30

Larkin, J 1981: Cognition of learning physics: Am J Phys 49 (6)

Lawson, A E 1979: Comment on "Cognitive level and college physics achievement"
Am J Phys 47 (7) 652
1982: The reality of generative cognitive operations
Science Educ 66 (2) 229
1983: Predicting science achievement: The role of developmental level
J of Res in Sc Educ 20(2) 117

Lawson, A E; Karplus, R et al 1978: The acquisition of propositional logic and formal operational schemata during the secondary years
J of Sc Teach 15(6) 454

Lawson, A and Renner, J 1978: Relationships of science subject matter and developmental levels of learner: J Res Sc Teach 15 465

Leboutet-Barrell, L 1976: Concepts of Mechanics among young people
Phys Educ 11 462

Libermann D and Hudon, H 1979: Correlation between logical abilities and success in physics: Am J Phys 47(9) 784

Lin, H 1983: Problem solving in introductory physics: Demons and difficulties
University Microfilms International Michigan

Linder, C J et al 1984: Improving concept formation and problem solving skills:
Paper given at S A Institute Physics conference Cape Town

Lythcott, J 1985: "Aristotelian" was given as the answer, but what was the question?
Am J Phys 53 (5) 428

Mahadeva, M N 1983: Misconceptions and myths masquerading as biological facts ..
In Helm, H and Novak, J [Eds]:Proceedings of International Seminar on Misconceptions in science and mathematics

Mallinson, G G 1977: A summary of research in science education -1975
New York: John Wiley & Sons 1977

Maloney, D P a 1981: Piagetian testing Am J Phys 49 (2) 190
b 1981: Comparative reasoning abilities of College students
Am J Phys 49 (8) 784
c 1984: Rule governed approaches to physics: Phys Educ 19(1)
d 1985: Rule governed Physics:some novice predictions
Eur J Sc Educ 7 (3) 295
e 1986: Rule governed physics:current in a series circuit
Phys Educ 21 360

McClelland, J A 1984: Alternative frameworks:interpretation of evidence
Eur J Sc Educ 6 (1) 1

McCubbin, W 1984: The role of logic in students' assessment of scientific
explanations: Eur J Sc Educ 6 (1) 67

Mehl, M C 1983: An analysis of the cognitive difficulties of disadvantaged
students: Paper given at S A Inst of Physics conference Pretoria
1986: Unpublished PhD Thesis U Cape Town

Mehl M C and Lochhead, J 1987: The South African Pariah: Pilot or Pilate?
Working Paper:University of Massachusetts, Amherst, U S A

Moorcroft, J 1983: An alternative method of investigating pupils' understanding
of physics concepts: School Science Review 64 561

Moose, W C 1983: A qualitative approach to teaching problem solving in college phys
University Microfilms International

Mouly, G T 1971: Readings in educational psychology; Holt Rinehart and Winston N,Y.

Mulopo, M M 1983: Effects of traditional and discovery instructional
approaches on learning University Microfilms International

Nordland, F.et al 1974: A study of levels of concrete and formal reasoning ability
in disadvantaged junior and senior high school students
Science Educ 1974 58 569

Northfield, J and Gunstone, R 1983: Research on alternative frameworks;
Implications for science Teacher Education:
Research in Sc Educ 13 185

Novak, J 1977: An alternative to Piagetian psychology for science and mathematics
education: Science Educ 61(1) 453
1978: A theory of education, Ithaca: Cornell University
1978: An alternative to Piagetian :Psychology for science and
mathematics education :Stud in Sc Educ 5 1

Nussbaum, J and Sharoni-Dagan, N 1983: Changes in second grade children's
preconceptions about the earth as a cosmic body
Science Educ 67(4) 99

Ogborn, J and Wong, D 1984: A microcomputer modelling system:
Phys educ vol 19 1984 138

Osborn, S G 1984: A simple analog useful in teaching of capacitors
Phys Educ 19 132

Osborne, R J 1983: Towards modifying children's ideas about electricity
Res in Sc & Technological Educ 1 73

Osborne, R ; Bell, B and Gilbert, J 1983: Science teaching and children's
views of the world : Eur J Sc Educ 5 (1) 1

Osborne, J and Gilbert, J 1980: A technique for exploring students'views of the world: Phys Educ 15 376

Osborne, R J and Wittrock, R 1983: Learning Science:a generative process Science Educ 67 (4) 489

Otero, J 1985: Assimilation problems in traditional representations of scientific knowledge: Eur J of Sc Educ 7 (4) 361

Perez, D G et al 1985: Science learning as a conceptual and a methodological change change: Eur J of Sc Educ 7 (3) 231

Perry, W G 1970: Forms of Intellectual and Ethical development in the college years Holt, Rinehart & Winston 1970 N.Y.

Peters, P C 1982: Even Honors students have conceptual difficulties with Physics Am J Phys 50 (6) 501
1984: The role of induced emf's in simple circuit Am J Phys 52 (3) 208

Piaget, J 1970: Science Education and the psychology of the child: trans; D Koltman Grossman Publishers 1970

Pines, A and West,L 1986: Conceptual understanding and science learning Sc Educ 70 (5) 1986

Pope, M and Gilbert, J 1983: Personal experience and the construction of knowledge in science: Sc Educ 67 (2) 193

Pope, M and Shaw, M 1981: Personal construct in education and learning Int J Man - Mach Studies 14 223

Posner, et al 1982: Accommodation of a scientific concept: Towards a theory of conceptual change: Science Educ 66

Preece, P F W 1976: The concepts of electromagnetism: etc J of Res in Sc Teach 13 (6) 517
1981: Proceedings of the International:Workshop on "Problems concerning students representation of physics and chemistry knowledge". Ludwigsburg, Germany 1981
1983: Research on Physics Education: Proceedings of the first International Workshop. La Londe Les Maures.
1984: Intuitive science learned or triggered Eur J Sc Educ 1984 6 (1) 7

Prosser, M L 1979: Cognitive analysis of physics textbooks to the tertiary or college level: Science Educ 63 (5) 677
1983: Relationship between the cognitive abilities of a group of tertiary students, and the cognitive requirements of their textbook Science educ 67 (1) 75

Psillos et al 1987: Students' representation of electric current before, during and after instruction on d c circuits Res in Sc and Tech Educ 5 (2)

Rachinger, W A: Electricity & Magnetism:diagnostic tests John Wiley & Sons Australia 1973

Reif, F et al 1979: Teaching Physicists skills in the laboratory Am J of Phys 47 (11) 950
1983: Teaching problem solving or other cognitive skills Physics Teacher May 1981 310

Renner, J W and Lawson, A 1973: Piagetian theory and instruction in Physics
Physics Teacher March 1973 165

1973: Promoting intellectual development through science teaching
Phys Teacher May 1973 273

Renner, J W and Paske, W 1977: Comparing two forms of instruction in college physics
Am J Phys 45 (9) 851

Rhoneck, C V 1981: Students' conceptions of circuits before Physics Instruction:
Paper presented at conference on "Problems concerning
students' representations of physics and Chemistry knowledge "
Conf.in Ludwigs'burg W Germany Sep 1981

Richmond, P 1982: Teaching about energy: Phys Educ 17 (5)

Riley, M S et al 1981: Representations in early learning: The acquisition
of problem solving strategies in basic electricity
Conf. Ludwigs'burg W. Germany Sep 1981

Roberts, D 1983: How batteries work:a gravitational analog
Am J Phys 51 (9) 1983

Rose-Innes 1985: Electromotive force: Phys educ vol 20 1985 272

Rosenquist, M 1983: Improving preparation for college physics of minority students
University Microfilms International

Schmid, B G 1984: An up to date approach to physics: Am J Phys 52(9) 794

Sears, Young and Zemansky 1980: College Physics: 5th Ed Addison Wesley

Semper, R et al 1982: Use of Interactive exhibits in college physics teaching
Am J Phys 50(5) 425

Seretlo, J R 1980: Science in a Black Milieu:Invited address: S.A Institute of
Physics Conference Johannesburg July 1980

Shipstone, D M 1984: A Study of children's understanding of Simple D C circuits
Eur J of Sc Ed vol 6 (2) 85
1984: On children's uses of conceptual models in reasoning about
electricity In Duit and Jung and Rhoneck
"Aspects of Understanding Electricity " p 73 [Keil IPN]
1988: Pupils' Understanding of simple electrical circuits
Physics Educ 23

Shrigley, R L 1983: The Attitude Concept and Science Teaching:
Science educ 67 (4) 425

Solomon, J 1984: Prompts, cues and discrimination: The utilization of two
separate knowledge systems.: Eur J Sci Educ 6 (3) 277
1985: The pupils view of electricity: Eur J of Sci Educ 7(3) 281
1987: Social Influences on the construction of Pupils' understanding
of science: Stud in Sci Ed (14) 63

Stanton, M 1987: Conceptual problems in simple circuits: Insights
gained from student responses etc; Paper given at
S A Institute of Physics Conference Natal July, 1987

Stavy R et al 1980: Cognitive conflict, a basis of teaching aspects of
the concept of temperature : Science Educ 64 (5) 679

Steinberg, M 1983: Re-inventing electricity : In Proceedings International Seminar:
Misconceptions in science and mathematics: Cornell Univ. Ithaca, N.Y. 1983

Thornthon, R K 1987: Tools for scientific thinking: Physics Educ 22 987

Trowbridge, D E and Mc Dermott, L 1980: An investigation of student understanding of the concept of velocity in one dimension: Am J Phys 48 (12) 1020
1981: Investigation of student understanding of the concept of acceleration in one dimension: Am J Phys 49 (3) 242

Viennot, L 1979: Spontaneous reasoning in elementary dynamics: Eur J of Sc Educ 1 205
1985: Analysing student's reasoning in science: A pragmatic view of theoretical problems: Eur J of Sc Ed 7 (2) 151
1985: Analysing students' reasoning; tendencies in interpretation Am J Phys 53 (5) 432

Whittles, P A 1983: Some problems in the development of Physical concepts among Basotho secondary school pupils: Invited address: S.A Institute of Physics conference July 1983

Warren, J W 1982: The nature of energy: Eur J Sc Ed 4 (3) 295
1983: Energy and its carriers; a critical analysis Phys Educ 18 209

Watts, D M 1982: Gravity: dont take it for granted: Phys Educ 17 (5)

Watts, D and Zylberstein, A 1981: A survey of children's science about force Phys Educ 15 360

Symposium on "The Undergraduate curriculum for Teachers of Mathematics and Physical Science: October 6 1986 Stellenbosch University