LEARNING BASIC ELECTRICAL CONCEPTS WITH MODELS AND ANALOGIES USING A MULTIMEDIA PACKAGE

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ABSTRACT

Secondary school teachers aim at helping their students to learn efficiently by using many exploratory treatments, especially in physics. Leading science educators and researchers promote learning by confronting students with the inconsistencies entailed by their own beliefs.

The thesis indicates that well designed computer based environments with models and analogies can provide advantages over many approaches using other media. The facilities provided by such environments can be exploited to promote cognitive conflict which is believed to be beneficial for learning.

Within the framework of using models and analogies to support learning science, the claim of the thesis is explored through:

the nature of students' beliefs about electrical concepts which are in conflict with scientific beliefs

the required prerequisites of computer based environments which can promote learning of these concepts through models and analogies

the issues which relate to educational theory and practice, students' learning & teaching, and the design of software using HyperCard techniques and multimedia for the creation of models and analogies.

Software was constructed within the framework of the design claimed by this research. Questionnaires were given to the students, and interviews and observations were made of their use of the software.

With reference to the results, an analysis is included of the use of models and analogies in teaching & learning science topics. The advantages and disadvantages of these kinds of computational environments for the improvement of students' learning are discussed in details mainly with emphasis on the nature of students' beliefs, which are deeply seated and persistent. The recommendations included focus on how such environments can be designed and constructed in the near future in order to create suitable mental models for a better understanding of electrical concepts and phenomena.

I DECLARE THAT THIS THESIS HAS BEEN COMPOSED BY MYSELF AND THAT THE WORK DESCRIBED IN IT IS MY OWN :

ZOE ZONI KAVOGLI

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CHAPTER 1
INTRODUCTION

It is well-known that in recent years Educational Technology has changed the traditional role of the teacher in the classroom. As a result, important improvements in the level of Education and the efficiency of teaching have been in progress. Microcomputers, accompanied by other media, are very powerful tools that are available to teachers. However, in the classroom there are two factors which interact with each other, the teacher and the students. The microcomputer plays the role of mediator between them. Thus, teachers use it as a teaching tool while students use it as a learning tool.

The fundamental concern of this thesis is the design and evaluation of teaching packages using HyperCard techniques and multimedia for first year University students learning about electricity.

During recent years there has been significant research work on exploratory learning (Vitor and Joao 1989, Niedderer, Schecker and Bethge 1991, Bliss et al. 1992, Farrow 1993, Gill and Wright 1994, Kavogli 1993 & 1995, Jones et al. 1996). There is also growth in the use of specific tools, such as HyperCard, and their evaluation (Taylor et al. 1990, Howe et al. 1990 & 1991, Blaye and Light 1992, Evans 1993, Waddick 1994, Harding et al. 1995, Cockerton and Shimell 1997). HyperCard is a powerful educational tool which allows us to organise information on computer, for example by hierarchy. The software allows us to merge different media -text, graphics, pictures, animation, sound and video- to create a wide range of applications. These present the possibility of improving the quality of Education, especially learning and teaching Physics' topics, in which most concepts and phenomena are abstract and difficult to understand. This kind of software helps students to build mental models which in turn helps them to understand the concepts and phenomena.

The aims and perspectives of this research are:

a) To create suitable mental models for a better understanding of the physics concepts and phenomena;

b) To motivate students' learning;

c) To activate their initiative and interests for the taught subject through the textual, graphic and audio design/presentation of these teaching packages, which are based on students' misconceptions or alternative frameworks in learning about electricity, and on HyperCard and multimedia versatility;

d) To create an interactive and exploratory computer-based learning environment.

The type of learning environment adopted falls into the modelling category, using hypertext itself as a way of representing concepts and also using the software to help students to construct accurate mental models in electricity. The next section features a brief discussion on this modelling framework.

To pursue the general goals of this research it is necessary to explore:
* Provision of simple modelling environments
* Importance of students' misconceptions
* Educational issues with reference to learning about physics

The rest of this chapter features discussions on the main concerns of the thesis:
* Research into students' physics misconceptions in the area of electricity
* The advantages and disadvantages of modelling environments
* Current work in providing modelling environments

This is followed by an overview of the thesis.

1. 1 RESEARCH PROJECT

The starting point of this research project was two articles in the European Journal of Engineering Education in which researchers claim:

> "... the change of emphasis on various conceptual aspects of circuitry at university level during formal lectures will have little or no influence on the students' misunderstandings. A more drastic approach, such as 'special designed' remedial activities integrated into normal classroom activities, might be more successful provided that these activities were based on a pedagogical model which took into due consideration the students' preconceptions..." (Picciarelli et al. 1991a).

They also recommend that physics teaching communities activate adequate strategies to improve their teaching, so that students can overcome their difficulties (Picciarelli et al. 1991b), as also mentioned in Gill and Wright's research (1994).

In this particular study, the interest focused on how the researcher can create remedial activities as described. Research done by Brna (1987) reinforced the researcher's intention to use computer-based exploratory learning environments, with a framework "based on a pedagogical model which took into due consideration the students' preconceptions" of the above mentioned activities.

The result of the above mentioned is that the area of this research is the design and evaluation of teaching packages using HyperCard techniques and multimedia for first year University students learning about electricity.

The design of this instructional software is based on students' misconceptions or alternative frameworks or the existence and persistence of misunderstandings of models of: current flow, voltage or potential difference, resistance, resistors in series and in parallel, and Ohm's law. This package consists of three parts.
The first part consists of ten questions with multiple choice responses. Subject domain feedback is provided by the "Hints" button (minimal guidance) and/or another button (more help) by which simulations and animated pictures are provided to extend or modify their models of electricity. The choice of the correct answer and the explanation which is provided to the "Why do you say that?" questions are fields of this research. Visual and sound effects accompany each interaction with the package as motivational feedback.
The second part is an exercise connected to a spreadsheet system that enables students to rapidly and easily make use of a computer's database and graphics capability in learning about Ohm's law. The advantages of spreadsheets relate to the possibilities of more open-ended investigations, more problem-oriented activities and more active learning situations.
The third part is an evaluation of the student's responses as recorded by the software. The actual evaluation was provided by the software. This is a type of motivational feedback which affects learner/computer interaction, one of the principles of the instructional design.

Students have deeply ingrained ideas about the nature of electricity which they bring with them to their physics lectures. By using the software they may be put into conflict with their own model, and are encouraged to question their model, extending or modifying it as necessary (conceptual change), so that learning takes place. Osborne and Freeman (1989) show that two types of strategy are introduced. Firstly, students are allowed to experiment in an open-ended way with circuit components. Practical problems in the form of questions are set and students are expected to answer by themselves, either with minimal guidance or with more help. Secondly, visible analogies and concrete visual models of simple electrical phenomena are provided.

1. 2 LITERATURE REVIEW

1. 2. 1 SCIENCE EDUCATION : Misconceptions or Alternative frameworks on Electricity

Much research has been conducted especially in the above mentioned topic of Electricity within science education.

a) Electric current

Fredette and Lockhead (1980) examined a set of experiments performed by University students using bulbs, batteries and wires. They noted that some students were familiar with electrical concepts and some still had "deep-seated" problems even though they had taken relevant courses.

Osborne outlined many problems in understanding electric current (Osborne and Gilbert, 1980). Students between the age of 7-18 were interviewed and only a small difference was found in their responses. Osborne (1981) also developed his ideas by describing three possible but incorrect electric current models.

Shipstone has expanded this work by establishing four models for electric current which include the "clashing current" model (Shipstone 1984). The evidence is that the use of this clashing model diminishes as students become older. More details on the above mentioned model and other kinds of models are provided later in Chapter 4.

Shipstone (1985) found that 39% of physics graduates who were training to become teachers used the "sequence" model. Also Licht (1991a) claims that sequential reasoning is very persistent with age throughout schooling. His findings indicate the effectiveness of a teaching strategy in a higher form of secondary education in which an explicit confrontation takes place between pupils' own alternative conceptions and some electrical concepts. In another article, Licht (1991b) introduced a microscopic model of current and voltage in order to teach the concepts to pupils in secondary education aged 13-18. In this way, the dynamic model has the potential to promote conceptual change according to pupils' differing conceptions. His findings are in agreement with those of Eylon and Ganiel (1990) who claimed that for a proper understanding of electric concepts students should be able to associate

macroscopic phenomena occurring in electrical circuits with microscopic processes.
Cohen, Eylon and Ganiel (1983) referred to similar problems in physics teachers' conceptual difficulties which can not be overcome even by more advanced studies of physics. Similar results were found by Kruger (1990), Summers (1990), Picciarelli et al (1991), Webb (1992), Stocklmayer, Zadnik and Treagust (1993) and Stocklmayer and Treagust (1996).

Hydraulic models of electrical concepts (Bauman 1980, Gentner and Gentner 1983, Black and Solomon 1987) are considered to be better analogies even for university students' learning about the behaviour of electrical circuits.

Anthropomorphic models have also been introduced as valuable teaching tools (Osborne and Freeman 1989) depicted recently by the use of delightful cartoons (Warren 1983, Shipstone 1988, Taber and Watts 1996). These are clear, amusing and provide concrete visual models of many simple electrical phenomena such as electric current. They clearly show that the carriers of charge are not "used up" as they pass through resistors and bulbs.

Both the above models are accepted because of their simplicity and familiarity not only by students but also by teachers (Black and Solomon 1987, Osborne and Freeman 1989).

b) Resistance
Several researchers reported that students tend to reason "locally" or "sequentially" about the effects of changes in an electric circuit. According to Riley et al. (1981), Closset (1983) and Shipstone (1984) if a variable resistor's value is altered they predict changes in meter readings "after" the resistor but not before. Cosgrove (1995) pointed out that students regard resistors as consumers of charge (consumption model for electrical resistance) rather than as a hindrance to the flow of current (hindrance model for electrical resistance).

Johnstone and Mughol (1978) investigated secondary school students' (S2 to S5) understanding of the concept of resistance. They focused on the relationship between resistance and the length and thickness of a conductor of uniform cross section. Their main recommendation is that the concept of conductance might be easier to teach than that of resistance.

Firstly, diSessa (1983) points out that many students are offered an explanation of Ohm's law in terms of phenomenological primitives (termed p-prims). In accordance to this, Ohm's law is a case of impetus against inertia which produces a result - the more you try to create an effect the more you will be resisted. Thus, impetus is related to the potential difference, inertia to the resistance and the result is related to electric current. Researchers claim that in many studies, where teachers used this analogy, results showed an improvement in students' understanding.

Many properties of resistive circuits can be analysed by using fluid-flow analogy. For example, an incompressible fluid starts flowing almost instantaneously throughout the whole system as soon as a valve anywhere in the system is opened if pipes are already full of fluid. This illustrates the electrical case where the drift speed of the charges is very small, but the current flows throughout the circuit almost immediately after closing the switch. Instead of fluids, moving blocks may be used which are raised by conveyor belts and then dissipate the energy by sliding down an inclined plane.
Another approach (Psillos and Koumaras 1993), which according to students' comments appears "attractive" because it relates to energy dissipation, is the analysis in terms of a model of the atomic processes involved in electrical conduction. In this model, the term "obstacle" is used for resistance. This analogy can explain the proportionality of resistance to factors such as length, cross section, material and temperature.

c) Potential, potential difference/voltage

Archenhold (1975) discovered some misconceptions or alternative frameworks about potential, which are:

* The potential across a resistor is the difference in the number of electrons at either end;
* A potential is a store of electrons.

Johnstone and Mughol (1978) also reported similar confusion of potential difference with other quantities such as power or electromagnetic force.

Studies on pupils' views about potential difference/voltage have shown that the learning/teaching of this concept is considered to be very difficult. According to Tiberghien (1984) many of them utilise the above-mentioned concept in ways which do not fit the accepted conceptual model. Similar cognitive behaviour is presented, not only by pupils at lower secondary school, but also by students at University level even after years of theoretical and experimental physics' teaching (Cohen et al. 1983). In DC circuits, pupils use the concept named "current" or "energy" which has the properties of movement, storability and consumption (Shipstone 1985, Psillos et al. 1986).

Voltage is considered as a property of current which indicates its strength, force or power (Rhoneck 1982, Rhoneck and Volker 1985). In their research, Psillos et al. (1988) claim that the majority of pupils aged 13-14 (66 out of 90) knew the term "volt" and they considered that it indicates the quantity of "something", e.g. "current" or "energy" that they use to interpret electrical circuits while the battery is considered as a container of "something". Pupils cannot recognise the existence of voltage/pd. as a necessary condition for current to flow in a circuit. Thus, pupils believe that the battery is a device which supplies constant current to the circuit rather than one that maintains a constant voltage across its terminals (Cohen et al. 1983).

The construction of the concept of voltage by pupils implies the differentiation between current and voltage, as well as between voltage and energy. In this case, pupils are asked to predict, compare and interpret bulb brightness and/or readings of a voltmeter and a ammeter respectively in different ways, as appropriate. Thus, the variables voltage, current, resistance and energy stored are necessary to study as a system (Hartel 1985 & 1993, Psillos et al. 1988). In many secondary school textbooks potential difference (pd.), EMF and voltage are used to describe DC circuits and electrostatic phenomena.

Confusion exists in the differentiation between the above three terms. The same confusion exists even at university level and in technical literature (Page 1977). Thus, voltage includes by definition both pd. and EMF and it is a generic concept. Its key aspect is that it is always concerned with what happens between ordered pairs in a particular system. In textbooks, authors often mention the voltage (potential) at a point for reasons of brevity and omit to mention that the reference point for voltage lies by definition at an infinite distance in space. Reference to points in a circuit, rather than ordered pairs is the source of confusion for pupils (Jung 1985).

Additionally, physical quantities which refer to "actions that might take place" like potential energy and voltage, are difficult for pupils to conceive. According to research carried out in Germany (Duit 1985) and in Greece (Koumaras et al. 1986) the break-through in pupils' understanding the essential features of voltage was discussion with them in terms of anthropomorphic arguments.

In a study, Millar and King (1993) proposed the introduction and development of the concept of voltage for pupils aged 15. This involved the predictions of voltmeter readings in circuits consisting of two resistors in series rather than directly probing pupils' ideas about voltage. Measuring voltages in such circuits provides some of the necessary data for moving students on from a simple model of voltage based on the "strength of the battery's push" (an EMF model) towards a model based on energy gains and losses (an energy per unit charge model). The latter model was presented in the instructional software of this research.

An alternative approach to teaching/learning about potential difference (pd.)/voltage is the use of models and analogies. Thus, with reference to the hydraulic model, the hydrostatic pressure is analogous to the electric potential (Iona 1979, Bauman 1980, Osborne and Freeman 1989). Another model is the "central heating" model (Dupin and Joshua 1989). In this model, the current is the rate of flow of water, and the boiler and pump correspond to the battery which supplies energy to the water. The energy is transported to the radiators where it is transferred to the internal energy of air. The radiator is not a constriction in the circuit but a very large pipe which offers low resistance to the passage of water.

In the teaching sequence proposed by Koumaras et al. (1986) the introduction of voltage should come after the pupils' familiarisation with series and parallel connections of batteries and bulbs. Current, resistance and energy stored should then be dealt with; therefore this sequence will result in the discovery of relationships between the variables (e.g. Ohm's law). Finally, pupils can relate microscopic events to macroscopic variables and so the microscopic description is in terms of non-observable events, such as "charge accumulates" or "chemical reactions take place" which leads to meaningful learning (Cohen et al. 1983, Eylon and Ganiel 1990).

d) Circuit analysis

Caillot (1985) believes that students form an initial view of what constitutes two resistors in series or parallel in a geometrical rather than topological sense. With regard to the conceptualisation of series and parallel connections, it seems that research has focused on bulb connections rather than on batteries. Thus, Licht (1985) reported that most pupils in secondary schools believed the connection of sources in parallel leads to a doubling of current in comparison to one source.

Shipstone et al. (1988) found in a survey covering several European countries, that many 15-17 year old students did not appear to understand that voltage is shared equally between identical elements in a series circuit. Millar and King (1993) also mentioned that in their test 30% of students gave answers which conflicted with the "addition rule" even though they had previously answered questions correctly. Additionally, they found that more students ticked the correct answer of the multiple-choice questions than students who had attempted to provide correct or partially correct explanations. Similar findings have also been noted by Rozier and Viennot (1990) and in this research as well.

Basing their findings on a short diagnostic test administered to 157 15-year-old pupils' work on electrical circuits, Millar and Beh (1993) found common errors in predicting voltage across parallel branches which suggest that only a minority of the pupils have a good understanding of voltage in simple parallel circuits. Most can not state with confidence that the voltage measured across each branch is the same. Their most common error was to halve the battery voltage when substituting for V in the equation $i=V/R$, apparently assuming that voltage was divided between the two resistors. Thus, it seems that most students do not have any physical model at all, but rather use the equation in a mechanical fashion, as Metioui et al. (1996) also pointed out.

Using analogies and "Modelling Analogies" in teaching basic electricity, Dupin and Joshua (1989) achieved a "structural isomorphism" between the electric circuit and the water pipes.

Cohen, Eylon and Ganiel (1983) devised a questionnaire to investigate misconceptions in simple circuits. They found that students saw current as a prime concept rather than potential difference and explained changes in a circuit by using "local" analysis. These results have been confirmed by other researchers (Black and Solomon 1987, Dupin and Joshua 1989, Duit 1991). For Ohm's law Dupin and Joshua (1989) suggested two analogies for an integrated conceptualisation of the law, the train analogy and the thermal analogy. The first has been proved effective for series circuits and the second for parallel circuits. In the first case, students easily accept that a local influence (breaking action) can influence the whole system (train speed). In the second case, students think that two resistors in parallel have smaller resistance than one (Closset 1983). This is brought into conflict with their preconceptions, which in turn leads to a significant improvement in their performance on questions about parallel circuits.

Finally, according to Dupin and Joshua (1989) and Duit (1991), modelling should generally be used with care and its limitations recognised. A detailed discussion on this topic is presented in the following section.

1.2.2 THE MODELLING APPROACH AS A KIND OF LEARNING ENVIRONMENT

The use of models and analogies : Explanation and prediction

The main functions usually ascribed to models are those of explanation and prediction (Gilbert and Osborne 1980). Harre (1972) makes the distinction between explanation and prediction clearer by describing the function of analogue models as logical and epistemological. Predictions are derived from logical deductions based on the model and explanations are based on the epistemological function.

An important contribution to effective teaching/learning is made by the teachers' understanding of the main topics in each subject area and knowing how to transfer their actual content knowledge into knowledge for teaching/learning. One teaching aid is the use of models and analogies which can effectively communicate concepts to students from different backgrounds and different prior knowledge. Indeed, Treagust (1993) claims that "models and analogies are considered to be an important component in the repertoire of effective teachers".

The heuristic uses of models and analogies

There is a heuristic value associated with the uses of models and analogies (Chalmers 1975). Hesse (1966) sees novel ideas growing from attempts to use analogies as sources of prediction, while Gee (1978) feels that a model enables the user to "see the forest for the trees". More informally, Gilbert and Osborne (1980) claim that as models are a caricature of reality they are used to polarise one's thinking by throwing certain features into sharp relief. They also observed that students often learn new concepts via models and analogies. Nagel (1961) outlines this usage as a means of quickly describing the rules of correspondence between theoretical terms and observable facts. Bullock (1979) sees models as having a psychological role in the classroom and Ormerod (1978) sees models as providing an opportunity to present ideas in a simplified way and provide a consistent explanation of physical phenomena.

Scientists, students and uses of models and analogies

In the history of science, models and analogies have been tools for discovery. For example Joannes Kepler developed his concepts of planetary motion from the workings of a clock (Bronowski 1973) and Huygens used water wave motion to understand light phenomena (Duit 1991). A key question for researchers is whether secondary students can economically and repeatedly employ the same analogical reasoning skills to understand a new phenomenon. Cosgrove (1991) answered this by describing how 14 year old boys discovered a valid model for an electric current using their own analogies. A similar question was asked by Wong (1993) when teacher trainees created their own analogies to explain three phenomena of air pressure.

One of the goals of science education is to get students to think and behave like "scientists". Scientists both build and use models and thus a picture of "the Model Builder as Mature Scientist" is needed. Contrasting students' model building with that of a practising scientist, Gilbert and Osborne (1980) note that the scientist builds up a mental "model" through continued experimentation and through previous experience, knowledge of theory and the imaginative use of analogies. This is not so obviously the case for school students as they are likely to have little chance for continued experiment, little ability to transfer learning from one area to another, limited background knowledge and are extremely unlikely to make constructive use of models and analogies. However, they can be expected to use analogies and models in an imaginative way (Driver and Easley 1978, Driver 1981).

Teachers, students and the uses of models and analogies

In this thesis, the researcher is looking at models which are built using a computer system. In this situation, the student explores the workings of a model which is, in principle, capable of being made completely explicit. This approach is closer to the Popperian approach to science, in that the model can be regarded as a hypothesis to be explored by the student who can then compare the model with what really happens (Pope 1985).

Since students often lack the background knowledge to learn difficult and unfamiliar topics in physics, chemistry and biology; one effective way to deal with this problem is for the teacher to provide a bridge between the unfamiliar concept and the knowledge which students possess. This bridge allows new, abstract and complex concepts to be easily assimilated with the students' prior knowledge so as to help them understand the concept. An analogy is a process of identifying similarities between two concepts. A familiar concept is referred to as the <u>analog(ue)</u> and the unfamiliar concept is called the <u>target</u> and is related to the scientific concept. Teachers should select an analogue from the students' knowledge domain in order to assist in the explanation of the target/topic. The analogue and the target share attributes which allow a relationship to be identified and contribute to the knowledge domain of teaching. However, there are features of the analogue which are unlike those of the target and these can cause impaired learning if incorrectly matched, as mentioned in the research findings of Champagne, Gunstone & Klopfer (1985) and Cosgrove & Osborne (1985).

Research has proved that the effectiveness of analogical instruction can be improved by training students in analogical reasoning (Friedel, Gabel and Samuels 1990). Indeed, several authors nominate analogies as candidates for generating conflict between students' and scientists' science (Cosgrove & Osborne 1985), as being important elements in the learner's conceptual development (Strike and Posner 1985) and as being an important component in the repertoire of effective teachers (Brown 1994, Ritchie 1994, Treagust et al. 1996).

The advantages of analogies in teaching & learning

Duit (1991) claims that analogies help students' learning by:

a) Providing visualisation of abstract concepts;

b) Linking students' real world with new concepts;

c) Increasing students' motivation.

The presence of pictures is an aid to understanding. Similarly, the presentation of a concrete analogue facilitates access to the abstract concept by pointing to the similarities between objects or events in the students' world and the phenomenon under discussion. Analogies can be motivational in that, as the teacher uses ideas from the students' real world experience, a sense of intrinsic interest is generated.

Little has been determined from empirical studies about the actual learning processes which are associated with analogy-assisted instruction, since most of the studies have only measured the students' recall of learned materials. It is not known whether analogies really do assist students to attain a level of conceptual understanding or whether students use the analogy as an effective algorithmic method to obtain correct answers. Nevertheless, there are benefits in using analogies to teach science.

From a teaching point of view, the use of analogies can enhance students' understanding, since they open up new perspectives. Additionally, this creates an increased awareness for the teacher to take students' prior conceptions into consideration. Hence, differences between students' ideas and the teacher's ideas become more evident.

The limitations of models and analogies

Despite the advantages of analogies as outlined, the use of this teaching tool can cause incorrect or impaired learning about the analogue - target relationship. For example:

1) The analogue may be unfamiliar to the student;
2) Analogies may be useful in helping students who primarily function at the concrete operational level (Gabel and Sherwood 1980), but if they lack visual imagery, analogical reasoning or correlational reasoning, then the use of analogies may be limited, despite the finding that they may be useful. Students already functioning at a formal operational level may have adequate understanding of the target and the inclusion of an analogy might add unnecessary information.
3) No analogue shares all its attributes with the target. The attributes not shared are often a cause of misunderstanding for students who attempt to transfer them from the analogue to the target. For example, when students attempt to transfer attributes to a target, they occasionally incorporate parts, or all, of the analogue structure into the target content rather than using the analogue attributes as a guide for drawing conclusions about the target. The result of this incorrect transfer is that when students are questioned concerning the nature of the target content, they will answer with direct reference to analogue attributes.

The need for analogical instruction

Research (Treagust et al. 1992, Dagher and Cossman 1992) suggests that when analogies are used in class they are frequently presented in a way which does not enhance their effectiveness. If analogies are to be used by science teachers, then a carefully planned pedagogy is called for, within which the analogies used are relevant to as many students as possible. Some models or teaching approaches for the reliable and valid use of analogies in classroom instruction have been produced. Four such models are:
a) Brown and Clement's (1989) Bridging Analogies
b) Dupin and Johsua 's (1989) Analogy Teaching Model
c) Glynn's (1991) Teaching-with-Analogy model
d) Zeitoun's (1984) General Model of Analogy Teaching (GMAT)
While it is not a specific teaching model for analogy use, Cosgrove and Osborne's (1985) four phase conceptual change model highlights the value of analogies by suggesting their inclusion in the challenge stage of teaching.

Research conducted by Treagust et al (1992) focused on the presentation of analogies in class in such a manner that their effectiveness was enhanced. Thus, teachers used enriched analogies and included them in their lessons (e.g. the concept of half-life in radioactive decay, the three different types of fields) in a manner similar to the approach taken by Glynn et al. (1991). The model described by Glynn et al. (1991) has six steps:
a) Introduce the target concept to be learnt;

b) Cue the students' memory of the analogous situation;
c) Identify the relevant features of the target concept and the analogue;
d) Map out the similarities between the target concept and the analogue;
e) Draw conclusions about the target concept;
f) Indicate where the analogy breaks down.

The results of this research showed that the use of analogies is of great importance in helping students to understand complex and abstract concepts.

Development and evaluation of analogical teaching & learning

As mentioned above, the effective use of analogies appears to be a natural approach for the introduction of complex and non-observable concepts. Building on this earlier work, Harrison (1992) observed that when teachers presented analogies systematically, the resultant student understanding was compatible with scientists' views. Harrison and Treagust (1993) predicted a report on the teaching of an analogy (the wheels analogy) for explaining the phenomenon of refraction of light. They mentioned that although the phenomenon was familiar to students its explanation was fraught with conceptual difficulties. After the lesson, Harrison interviewed all students and the teacher. He also administrated analogical mapping charts to students. The analysis of these data clearly indicated how the teacher had utilised all of the six steps of the Glynn model for analogical instruction and that this teaching approach was effective in enabling students to describe and explain the phenomenon better.

Three months after the lesson on light refraction, Treagust et al. (1993) interviewed all students from the class that had been taught the wheels analogy. They also interviewed a parallel class in the same school taught by the same teacher, which had not received analogical instruction. The results from the interviews on different aspects of refraction illustrated that the students taught with an analogy were able to explain phenomena not previously seen and had understood the crucial aspects of refraction far better than those who had not been taught using analogies. Thus, Treagust et al (1993 & 1996) hypothesised that the analogical instruction appeared to provide students with conceptual change.

The experience of the above mentioned research group enabled them to develop a simpler model than that of Glynn's. This was an effective and efficient three-phase model of analogy teaching. The three phases of the teaching approach are F(ocus), A(ction) and R(eflection), which form the acronym FAR (fig. 1-1). Its purpose is to help teachers maximise the advantages and minimise the constraints of analogies as they arise in classroom discourse.

FOCUS

CONCEPT	Is it difficult, unfamiliar or abstract?
STUDENTS	What ideas do the students already have about the concept?
ANALOG	Is it something that your students are familiar with?

ACTION

LIKES	Discuss the features of the analog and the science concept. Draw similarities between them.
UNLIKES	Discuss where the analog is unlike the science concept.

REFLECTION

OUTCOMES	Was the analogy clear and useful, or confusing?
IMPROVEMENTS	Refocus as above in light of outcomes.

Figure 1-1
The three aspects of the FAR guide for teaching and learning with analogies
[from Treagust et al. (1993) p.299]

The model has come as a result of many hours observing and interviewing teachers and students. It has been designed, as much as possible, to reflect the skilled way in which a teacher can use analogies while teaching science topics. Most importantly, preliminary research based on the FAR model indicated that both teachers and their students benefited from and enjoyed analogies when teaching and learning about science.

Learning about electricity with models and analogies

Research findings indicate that it may be ineffective to present a principle with supporting examples to show the range of applications of the principle to students who hold a misconception. It appears that examples are more effective when they help students to draw on and analogically extend existing valid physical intuitions in constructing a new conceptual model of a target situation. Following long-term research, Brown (1992 & 1994) came to conclusion that the use of concrete examples and analogies/models can be an effective means for inducing conceptual change. They help students to develop visualizable, qualitative, mechanistic models of physical phenomena, which in turn can assist students to make sense of the more abstract principles often invoked to explain the phenomena.

Fowler (1982) also indicates that the intimate, intuition-based interaction between theoretical system models and a user can lead to a creative form of model exploration through a computer programme. This is because the user can explore the model's behaviour and the role of each constraint of the model. As each model is explored assumptions are changed and a new model is created, which in turn is explored, and gradually the user develops a model with realistic behaviour. Thus, model building supports the inductive forms of learning and visualisation of complex phenomena.

In the domain of electricity no acting mechanisms can be seen, only effects, so learners reason with analogies taken from more familiar fields -especially mechanics. As mentioned above, Bauman (1980) reports that hydraulic models deal with the kind of fluid with which students have some direct experience and that they are helpful in illustrating the behaviour of electrical circuits, especially for transient and resonant phenomena.

In their research, Black and Solomon (1987) reported two popular analogies for electric current flow. Both are commonly used in schools. One is the flow of fluid down a pipe and the other is the movement of some imagined particles or cars (sometimes called electrons). Research findings indicate that although both analogies work equally well for the pupils, there is evidence that the electron analogy might have the stronger appeal. Almost 60% of each analogy group used their analogy at least once, but pupils of the electron group used their analogy repeatedly. Finally, this study supports the constructivistic view of learning because pupils were encouraged to link new knowledge with old through an analogy. Pupils not only solved predictive problems better, but also spontaneously drew on their own analogies in both interview and free writing. Similar findings are discussed in Chapter 4.

It is very common that many students experience confusion in understanding current and voltage, and, frequently use the two terms as if they were interchangeable, when attempting to describe what is happening in the circuit. In an attempt to clarify these concepts many teachers resort to analogies, the most common being the flow of water.

From his research with classes ranging from second year up to the end of secondary school, Jeffrey (1978-79) proposed two other interesting analogues, one for potential difference and one for resistors in series.
In the first case, the analogue unit consists of an array of polystyrene spheres mounted on the ends of small expandable springs which in turn are mounted on a board. The spheres represent the atoms in a conductor and a large ball bearing is used to represent an electron or a charged particle depending on which stage students have reached. Rolling the ball in at one end results in a few spheres vibrating and the ball quickly coming to rest. By referring to the particulate nature of matter students should be able to state that the polystyrene spheres should be vibrating. As a result, pupils suggest raising one end of the board. Then the ball travels down the board in a random fashion, leaving behind an array of vibrating spheres. Finally additional ball bearings are allowed to "flow" through the "conductor", and doubling the height increases the rate of "flow".
In the second case, two boards are used with a short friction compensated between them to illustrate resistors in series. As in the first case, the analogue has met with success because students state that, for example the initial potential energy of the ball is shared between the two boards; charge flowing through two resistors in series shares its energy between them; total energy/coulomb = energy/coulomb lost in 1 + energy/coulomb lost in 2.
In both cases, students conceptualise the electric circuit as a system because, according to Eylon and Ganiel (1990), not only do they appreciate the "quantitative" and the "functional" relationships between its parts but also they think in terms of those aspects of the processes where the macroscopic circuit parameters are tied with microscopic models and rules.

The train and thermal analogies were introduced to secondary school students (grades 6 to 10) by Dupin and Joshua (1989). The train analogy appeared to supply an interesting aid for differentiating between energy and material aspects of current flow and for overcoming the misconception of "current consumption". Thus, it is effective for series circuits while the thermal analogy (presented in the metaphorical form of the workings of a refrigerator) is effective for parallel circuits because the second analogy allows the notion of potential to be introduced, as well as Ohm's Law in its localised form.

In other research with younger pupils (14 years old) Cosgrove (1991 & 1995) claims that the pupils could economically and repeatedly employ analogical reasoning skills to understand electric current.

Jabin and Smith (1994) interviewed a sample of 24 children aged 9-10 and noted the changes in children's ideas after they had been taught with analogies (water flow, moving blobs, moving trucks). Their results show that for the particular sample used the analogies were successful in helping many of the children modify their ideas towards a more scientific understanding. Many pupils were able to understand the way analogies represented observable phenomena because they correctly answered most of the analogy worksheets. As a conclusion, these findings indicate that even at an early age pupils could use analogies to improve their scientific understanding of current flow. Such early modifications might also help pupils at a later stage where analogies with which they are already familiar could be used again to further their understanding.

1.2.3 IMPLICATIONS OF THE USE OF I.T. ON SCIENCE EDUCATION

In December 1993, part of the NCET programme was the Future Science Curriculum under the influence of I.T. from the earliest days of CAL (Computer Assisted Learning) up to the most recent interactive multimedia.

Educational processes can be influenced by I.T., through more flexible learning methods. Educators' current update experience shows that flexible learning strategies and the use of I.T. to support learning influence science at least as strongly as other subjects. There are pressures on the educational system to use its resources more efficiently and to increase the quality as well as the quantity of education within current budgets. Many claims are made for the contribution of I.T. to all levels of Education and especially within current expansion of post-16 and Higher Education (Harris 1994, Frost and Wardle 1995).

The whole field of instrumentation, measurement (using sensors), acquisition and handling of experimental data (data capture and processing by computers) has fundamentally changed. For example remote sensing, whether through earth observation, outward looking instruments (e.g. the Hubble telescope) or looking inwards into matter (e.g. ultrasonic and magnetic resonance body scanning) is a new field. This kind of development has radically changed the nature of scientific enquiry and experimentation, as well as what can be quantitatively observed, the accuracy of measurement and the facility with which the data can be manipulated.

Theoretical and mathematical predictive modelling has for a long time been part of the armoury of scientists in developing, testing and explaining concepts and theories. In particular, physics which is a highly conceptual discipline, involves theorising and the use of mathematical models to explore the implications of theories and to make testable predictions. This requires learning about the different methods of modelling, learning to construct models and critical appraisal of theoretical models.

There have already been indications of the significant influences of I.T. on the pedagogy of science. For instance, the use of computer graphics to represent chemical molecules can provide valuable insights into complex phenomena. In teaching ecology, the use of simulation models has added extra dimensions and opportunities under controllable conditions. Appropriate use of CAL, possibly in the mode of a game, can give improved access to important scientific ideas for many students.

1. 2. 4 MODELLING/SIMULATION COMPUTER ENVIRONMENTS AND CONCEPTUAL CHANGE STRATEGIES

A computer programme that supported either a modelling or simulation environment, would allow students to manipulate the objects in the model, and obtain feedback on the behaviour of the system in terms of the results of their manipulations. As Laurillard (1988) claims, these programmes have two important pedagogical features that conventional tutorials do not have:

a) They can give learners direct access to the object domain

b) They can give explicit intrinsic feedback on learners' experimentation within it. This is the type of experience which is needed by learners to develop their own understanding of a domain.

Recent educational research (Wild 1996) has shown that learning should be seen as a qualitative change in a person's way of conceptualising something in the real world rather than as a quantitative change in the knowledge possessed. Thus, learning techniques and teaching strategies are inextricably linked to subject matter and to the learners' perceptions. Understanding students' thought process should be an integral part of teaching and is the key to unlocking the door to better understanding.

In the above mentioned framework, microcomputer programmes have been designed in accordance with a model of conceptual change to diagnose and remediate alternative concepts in various subject domains. For example, in physics, with regards to the concept of velocity Zietsman and Hewson (1986) show that microcomputer simulations are credible representations of reality and the remedial part of their programme produced significant conceptual change in students' holding an alternative concept.
In other research (Flick 1990) sixth grade pupils interacted with a simulated, frictionless object using Logo turtle-graphics. When they were interviewed during the simulation about the perceived relationship between keyboard input and turtle behaviour, the turtle was related by analogy to useful information from existing concepts of motion. In fact, the researcher concludes that the analogies used by pupils allowed them to map out critical physical relationships between real-world concepts and simulated ones. Also similar findings are mentioned by Gentner (1988), Gentner and Toupin (1986) and other researchers (Treagust et al. 1990, Cosgrove 1995).

1. 2. 5 HYPERCARD TECHNIQUES AND OTHER MULTIMEDIA PROGRAMMES

a) In general
Since Apple Computer introduced HyperCard in 1987, there has been increasing excitement about the educational potential of interactive multimedia tools. Two types of products have appeared in the market place : tools and educational products. Their difference parallels a difference in beliefs about pedagogy and the nature of learning, and the educational role of interactive multimedia programmes.

On the one hand, tools are consistent with the view that knowledge is actively constructed by the learner.
On the other hand, most interactive multimedia educational products are closed systems with subject matter information in various formats and with certain pathways to explore, representing themes in the topic. They are considered to make interesting teacher presentation materials and resources for student research. Additionally, interactive hypertext environments encourage users to construct representations of their own understanding.

HyperCard and Hypermedia systems are believed to represent the way that a human being thinks (Bush 1945 & 1986, Kearsley 1988). It has been claimed that they will change education by enabling users to explore, create and construct knowledge as has never been done before (Abron and Hooper 1988). HyperCard, one of the new Hypermedia programmes, was proposed by Camp and Cogan (1988) to represent a milestone in educational computing and to offer enormous potential for education. According to Megarry (1988), Farrow (1993) and Cockerton & Shimell (1997), learning via Hypermedia systems, such as HyperCard, makes learning more effective as it gives the learner more autonomy.

Promises regarding the educational potential of HyperCard and other Hypermedia systems (Camp and Cogan 1988, Sculley 1988) have been rapidly followed by advice to be cautious about Hypermedia (Jonassen 1988, Smith and Hahn 1989, Locatis et al. 1990). According to Locatis et al. (1990) not enough research has been done because the use of authoring tools in Education, such as HyperCard, has only recently been adopted. Many ideas have been expressed, but mainly by practitioners. Systematic research has just started. Thus, there is little empirical evidence of HyperCard and Hypermedia's effects on learning. Students sometimes appear to have difficulty relating to the cognitive model of Hypermedia lesson construction. Smith and Hahn (1989) suggest that learners who prefer guided learning rather than independent exploration may become "lost in hyper space" as a result of them becoming disorientated in the environment.

However, Locatis et al. (1990) maintain that Hypermedia software is geared for information retrieval. They acknowledge that it might be useful in teaching the process of information retrieval in courses such as medicine, where programmes are becoming increasingly used for access to information.

Blaye & Light (1992) have done two studies: one with 11 year old pupils and the other with adults. While using a HyperCard environment in history lessons they pointed out that as a tool for problem-solving, a notable feature of this environment, compared to paper and pencil, was its interactive nature.

Similar results are indicated in another study (Kavogli 1993), observing 10 -13 year old pupils creating and using (navigating) stacks in science topics. Various problem-solving activities undertaken by them produced the development of particular skills connected with problem-solving, investigation and reasoning. Thus, the distinguishing feature of HyperCard is that it provides a framework for learning. The study also highlighted HyperCard's effects on an individual pupil and on pupils working together. From a questionnaire and observation notes, HyperCard was shown to be a really friendly environment for learning as pupils showed positive attitudes to HyperCard (e.g. they enjoy creating their own stacks and most of them do their best to create stacks).

Gill and Wright (1993) mention that although students' general perception of computer aided learning is that the packages are of poor quality, difficult to use and of no interest, Hypermedia systems can provide many links and cross-references, so that users can explore their own interests and branch when they feel it is correct to do so (McAleese 1989, McAleese and Green 1992). They also found that their packages were flexible, engaging and concentrated on offering a more individual approach. They allowed users to explore pre-instructional ideas and to try new approaches to equip themselves better and to provide richer learning.

Finally, HyperCard as a multimedia environment on the Apple Macintosh has offered the potential for the creation of a new generation of educational software for schools. It has a natural style of interaction overcoming many problems which have limited both software creation and software use in schools (Cockerton and Shimell 1997). From the multimedia viewpoint the key feature of HyperCard is that it is "extensible"; it allows "external routines" to be created which effectively add new commands to the HyperTalk Language. Essentially "resources", compiled from written code in C or Pascal, may be attached to a stack (or to HyperCard itself) and can be used to cover omissions or inefficiencies in HyperTalk or, more interestingly, they can be used to give access to other applications, such as Pascal and C programming languages and multimedia development tools such as a picture scanner, a sound digitiser, or a video frame grabber.

b) In various subject domains

It is common knowledge among educators that illustrations - which aid text and verbal explanations - show improvements in students' achievements. This is particularly the case for the HyperHeart programme which was used by 14-16 year old students for many years, Spencer (1990) mentions that such a medium enables the average student performance to reach the top level while conventional media fail to do this, as they are essentially passive and non-interactive. The researcher indicates that even students of low ability have persevered and mastered the material, and have also gained a more positive self-image in the process. Similar results come from this research and will be discussed later. He also concludes that the power of illustrations as an aid to understanding and their importance in maintaining perseverance has been amply demonstrated in preliminary experimental studies. Additional time, from 25% to 100%, was required to master the subject. However, in all cases students have felt that the extra effort has been worthwhile, as also shown in this particular research.

The "Self-Spell" programme designed by Nickolson (1991) is an attempt to remedy established problems of computer-based presentation for dyslexic children. Observations showed considerable enthusiasm and good improvement in the spellings targeted by the programme. All 15 pupils aged 8-13 and their parents reported that it was fun to use the programme. Open ended comments were uniformly enthusiastic. The research showed that there were two crucial advantages of this programme:

a) the ease of use

b) the ease of creating simple stacks for topics which could not have been easily taught using earlier educational software.

Hughes (1991) mentions that system developers find that static documentation is unsatisfactory as an instrument for understanding the real behaviour of systems in action, and as a means of communicating to users how a proposed system will work in practice. In order to combat this problem, moves have been made to develop systems which allow the execution or the animation of system specifications, and the use of prototypes is increasingly being embraced. The researcher concludes that in the teaching of computing subjects the use of HyperCard is a promising approach because of the use of pictorial or diagrammatic representations of algorithms. Students new to computing also find it hard to grasp the method of operation of various file organisations. Dynamic HyperCard representations of the processes involved seem a promising way to overcome these problems. Finally, the researcher claims that HyperCard contains not just the means of using already produced material, but also has bound into it the means of production. Thus educators can develop their own stack and swap it with the colleagues. They can modify other people's stacks for their own use as well, as mentioned by Anderson, Knussen and Kibby (1993).

As Nielsen (1990) mentioned, Hypertext type programmes can be valuable in learning a foreign language. The NICOLAS project for learners of French (Evans 1993) showed that:

a) The integration of text, sound and visual data is clearly beneficial to the learners as it reinforces comprehension, pronunciation and contextual use in a way that traditional materials are not able to do.

b) The inclusion of a dictionary facility was well accepted and supported with positive comments by learners.

c) According to the National Curriculum there is a link between the development of reading skills and the need to develop pupils' ability to learn independently (Po S1,6). Thus, the researcher but also Dennis (1992) claim that Hypermedia is a vehicle for the specific issue of developing independent, extensive reading competence because of the multiple routes to navigate.

As McKnight et al. (1989) pointed out, the book metaphor was used because it helped users, particularly novices, to "conceptualise" the electronic environment they were required to manipulate by relating it to a familiar context. A "map" of the available routes was considered to be a useful source of reference for the user to navigate effectively.

Similar findings about the impact of embedding a map into a computer courseware are reported by Barba (1993) after she evaluated the use of a HyperCard stack on volcanoes with high school students. She concludes that the map is an externally supplied graphic organiser which allows students to interact with the computer and to control the sequence of instruction, gives him/her feedback on his/her progression in mastering the content of the courseware and provides a graphic representation of the content of the courseware and the resources available.

From the records of pupils' performance on NICOLAS, Evans (1993) claims that the project promotes language learning on an intermediate level and there is, undoubtedly, a pedagogical benefit in being able to monitor each individual's use of the programme. It is a significant fact that a slightly higher percentage of picture and sound definitions were called up than English definitions. Pupils' attitudes about the software were positive, as proven in this particular research. Their comments, in general, were:

"interesting", "a little difficult", "more time to complete", "learnt new words", "dictionary system useful", "want to read more 'Petit Nicholas' stories", "want to read more stories on a computer".

In the article "A case study: The use of HyperCard simulation to aid in the teaching of laboratory apparatus operation" Waddick (1994) indicates that the operation of a spectrophotometer can be effectively taught by simulation. The students' impression was that the computer acted as an effective tool of instruction in the operation of this particular machine. These findings support both the use of simulations and spreadsheets. Similar results were provided by Hodson (1988), Hooper (1988) and Van dam (1989) on simulations, and Edwards et al. (1992) on spreadsheets.

Cockerton & Shimell (1997), Farrow (1993), Trentin (1992), Matta & Kern (1989) and Dawson (1988) claimed that computer environments, such as HyperCard and multimedia systems, provide active learning and are a way of helping students to improve knowledge.

Recently, Harding et al. (1995) developed a graphical toolkit for HyperCard as a support to their work in writing mathematics material (graph plotting in two or three dimensions including material such as matrix operations, solutions of differential equations, Fourier transformations etc.). Where presentation and ease of control by the user are uppermost considerations, the researchers conclude that the Graphical Toolkit adds to the usefulness of HyperCard as an authoring system for any mathematical related courseware by providing mathematical graphics facilities. Any modular software design can be successfully grafted onto HyperCard. Such a design contributes significantly to both quality and quantity of courseware for subjects with mathematical content.

In other research the focus is concentrated on the collection of information about the process rather than the product of thinking. Singley and Taft (1995) present examples from their work in the domain of designing chemistry problem solving interfaces (on chemical reactions, use of periodic table and scoring programmes). The technology is used to gather and analyse intermediate solution steps in order to gather information about the users' product and also their thinking process. Thus, they evaluate not only the correctness of response but also the quality of reasoning/thinking which generated the response. This particular research is currently in progress.

c) In physics
In their paper called: "A direct manipulation micro world for vertical motion" Hennessy et al. (1990) describe the theoretical and empirical steps taken in constructing their first computer-based micro-world for linear vertical motion under gravity, which was programmed in HyperCard for Apple-Mac IIx and tested on 15-year-old students. The DM-based pinball micro-world was found to be highly successful in eliciting prior conceptions in that domain. It enabled pupils to express the logic behind their reasoning and on the whole the interface proved to be transparent and realistic, as in the study on the creation and use of HyperCard stacks in science subjects (Kavogli 1993).

Similar results have also been found by Taylor et al. (1990), as noted in their project "The Computer Supported Collaborative Learning in Physics". The research was based on empirical studies of pairs of 12-15 year old students solving physics problems on mechanics, using a direct manipulation package running on an Apple Macintosh computer with the use of HyperCard. Researchers also indicate their software package supports collaborative learning.

In addition, Tolmie, Howe and Anderson conducted several studies on peer interaction in mechanics through a HyperCard stack with science and art undergraduates. The software causes a strategic conflict which becomes a source of conceptual change. In their article entitled "IT and group work in physics", Howe, Tolmie and Anderson (1991) addressed the consequences of 12-15 year old pupils' exchanging ideas whilst making joint decisions on the paths of the falling objects. This indicates the benefits gained by this particular process.

Gill and Wright (1994) explored student-driven computer based learning packages on Newton's Three Laws of Motion, and both elicit the students' own misconceptions and allow the students to learn at their own pace. This strategy also prevents the teacher-student-teacher sequence of inherited misconceptions (transmission model) and provides students with stress-free education (Anderson, Knussen and Kibby 1993). Actually, Gill and Wright's packages (1994) present students over 16 and 1st year undergraduates with ideas and information on physical phenomena. The students are asked to select the correct solution, chosen from a number of commonly held models for that particular Newtonian event. Students are shown a series of challenging cards and asked to explain why things happen, allowing them to see the consequences of applying their own ideas.

As mentioned in previous research, Wright (1991), Gill and Wright (1993) claim that the learner needs to build his/her own new model with careful guidance from the system, and carefully structured Hypermedia document (McAleese and Green 1992, McAleese 1989) as well as the tutor (Ausubel and Robinson 1969, Vygotsky 1986, Brown 1992 &1994).

Although much has been written about the benefits provided by Hypermedia, little has been reported on the qualitative and quantitative assessments of how these packages are used and their usefulness. Thus, Honey (1993) and Gill & Wright (1994) are confident that these systems can be used to enhance science teaching, provide better understanding and inspire more students to pursue a scientific career. All students stated that their learning was stimulated at a higher level and they were pleased with the practical examples.

Similar comments and attitudes have been reported not only in this particular research but also in that of Watkins, Augousti and Caverley's (1997) research on the evaluation of a physics multimedia resource project. entitled SToMP (Software Teaching of Modular Physics). The development and the evaluation of this project involved academics and researchers at many UK universities. SToMP uses the Microcosm hypermedia document management system to present and cross-reference teaching scripts, graphics, audio-visual materials and interactive simulations on the computer, together with various software tools for processing data, graphs, mathematical expressions and text for a complete learning environment.

1. 2. 6 SCIENCE EDUCATION WITH AN EMPHASIS ON ELECTRICITY AND IT

It is frequently observed that students face difficulties in the manipulation of basic facts and equations related to electric circuits. Furthermore, many researchers claim that the fundamental principles of physics need to be learned.

White and Frederiksen (1988) and Vosniadou (1992) assume that students:

a) Construct a mental model from the current computer-based symbolic model and

b) Then, having been exposed to a new computer-based symbolic model, transform the appropriate mental model into a more elaborate one.

Based on the above work, Brna (1987 & 1988) addressed a particularly interesting issue: what happens when a student's mental model is in serious conflict with the computer-based symbolic model. The researcher constructed a programme of work undertaken by 8 students (S4 and S5). This entailed the development of a computer-based modelling environment called ELAB. Brna's principle of design was that students should be able to model electrical circuits at a level which permits them to express some of their own beliefs about electrical concepts. The results showed that such an environment provided advantages over approaches exploiting other media because it provoked intellectual conflict, which in turn is beneficial for learning.

A survey was conducted by Oakley (1991) to determine the effectiveness of the courseware available to students enrolled in the introductory circuits analysis course in the 1990 Fall semester. He reported that the "HyperCard Courseware for Introduction to Circuit Analysis" provided individual feedback to each student. It also helped students to monitor their progress, to discover which topics they understood clearly and also which topics needed more attention. 85% of the students reported that the courseware was "very helpful" or "somewhat helpful". When asked what they liked most about this courseware, they commented: "the tutorial mode is like having a teaching assistant to work with you for as long as you need", "they make learning fun", "I like the tutorial mode - unlike homework". The average students benefited most from the use of the courseware, while the best students could effectively learn the course material on their own. Thus, in the 1990 Fall semester, when the courseware was used, the students' average performance in the exam was higher (80%), even though the exam was more difficult than that given the previous semester where the average result was 65%. Overall, it appears that this HyperCard courseware provides an effective mechanism for students to understand circuits analysis.

Conceptual change theorists such as Posner et al. (1982) state that effective instruction develops methods to overcome students' incorrect preconceptions and provides further development of appropriate conceptions. To overcome incorrect preconceptions, instruction must lead students to become dissatisfied with their own preconceptions and provide an alternative model which they perceive as "understandable", "plausible", "fruitful" or "generalizable".

Wang & Andre (1991) and Chambers & Andre (1990, 1991) used the approach of Posner et al. (1982) to compare traditional text (TT) and conceptual change text (CCT) and found that the latter led to a better conceptual understanding of electricity. Also, Carlsen and Andre (1992) showed the value of simulations and the conceptual change approach. They proposed that it is important for students to be given the opportunity to use these kinds of learning environments at an early stage in their experience of electricity. They claimed that these environments can enhance the effects of both CCT and TT because, CCT activated students' preconceptions and TT provided evidence that their preconceptions were wrong.

Furthermore, by using simulations and actively testing their preconceptions students became more knowledgeable than those who had simply read the evidence that the preconceptions were wrong. In this study, the simulation used was a HyperCard stack in which any electrical circuit mentioned in the CCT and TT could be designed and tested. Students could build a circuit by clicking on icons representing the electrical parts and moving these parts to the desired position. CCT led to significantly better students' performance, than did TT, confirming the previous findings of Wang & Andre (1991) and Chambers & Andre (1990, 1991).

The findings are of importance because the students were novices and only participated to earn an extra credit. The CCT manipulations and the simulation may be likely to have greater effects on students who were studying electricity in a real class. Students who used the computer simulation were likely to acquire a more advanced model of series circuits than students who had not. However, they did not differ significantly on total post-test score. The results suggest that simulation was beneficial in helping students to overcome incorrect preconceptions.

The researchers stated that the combination of CCT and simulation could not be assessed as being more effective than either one alone because of technical difficulties, such as: insufficient time for students using the simulation; memory and hard-disk limitations; slow response speed of the simulation; how students' sensitisation is assessed etc. Finally, they proposed that further research, using faster computers and better software tools, would prove whether simulations are efficient both when used alone and when used in conjunction with CCT. On this point, this particular research makes a similar proposal. Although the software was primitive in construction, the results of the research showed that students improved their learning about electricity by using this simple software.

A computer based version of the Electrical Engineering Aptitude Test has been developed in the Department of Electrical Engineering at the University of Sydney in conjunction with the University of Cracow, Poland and the University of Cape Town, South Africa. The test consisted of 32 multiple choice questions and required a basic knowledge of physics (circuit structure and topology, connection between resistors to determine Rtot, Ohm's law and Kirchhoff's rules). Pudlowski and Rados (1994) indicate that computer technology provides effective methods for testing because:

1) Electrical circuit diagrams and display instructions were presented on screen;

2) Answers could be selected from those on display by simple key-strokes;

3) Help screen and skip-question facilities were available;

4) Time performance and student records were available;

5) Quantitative analysis of individual student performance was also on display;

The test demonstrated that an interactive, human-machine type of testing can be successfully achieved (students' ability to interact with computers is assessed, students' aptitude for electrical engineering studies is also measured).

Alberto Silva (1994) simulated electrical circuits with an electronic spreadsheet; this can be an effective modelling tool for studying electrical circuits. Matrix algebra was used to calculate the amplitude of current and size of potential differences from Kirchhoff's Laws. At the beginning of the course a pre-test was used to determine students' concepts about the basic aspects of electricity. The pilot experiment took place after covering basic aspects of the field, both in the laboratory and in lecture classes. The sample consisted of 17 trainee teachers who specialised in Mathematics and Science. The researcher concludes that the effectiveness of the spreadsheet model is attributed to:

1) The absence of wires and other hardware, which provided students with a time effective environment;

2) The provision of an intensive and pleasant way of experimenting and also focusing students' attention on fundamental electrical aspects;

3) The possibility of testing in ideal conditions and in cases which are very difficult to implement in real circuits;

4) The provision of various cognitive conflicts between intuitive and scientific ideas and assistance in clarifying ideas and overcoming misconceptions.

Additionally, the students' attitudes to the software were positive as "they worked with impressive commitment and concentration" and "stayed after the lesson was over" and carried on working "during the lunch time". Similar students' attitudes are mentioned later in this research, as well.

In another paper, Alberto Silva (1995) after further development of the above mentioned spreadsheet, provided a system where more topics, such as Joule effect, conservation of electric charge and energy, load adaptation and power of transmission, equilibrium state in a current divider etc. could be studied. These topics would otherwise not be accessible to students because they would require a higher mathematical background. He also proposed that spreadsheets enriched with such capabilities can be used as powerful tools in studying the essential aspects of electric circuits. This allows efficient problem-solving tasks to be done even with a relatively poor level mathematical background. This work has been developed in the content of a more general research programme in the area of teaching & learning and is continuing progress.

Baxter (1995) did a comparative study between two methods of assessing students' learning of simple electrical concepts.
One method involves manipulation of icons on a computer to solve problems on electric circuits.
In the hands-on investigation, students are presented with equipment and asked to conduct an investigation to determine the content of six mystery boxes from a list of five possible options.

The "Electric Mysteries" computer simulation was developed in a Macintosh environment so as to replicate as closely as possible the hands-on investigation. The screen was divided into three sections: equipment pallet, work space and control panel. To begin the simulation, there is a brief tutorial illustrating the use of the software. Wires are drawn by clicking at one terminal of a circuit element and dragging to another terminal. Wires are removed by double-clicking. Students could connect many circuits on the screen at once. Alternatively, they could leave one completed circuit on the screen for comparative purposes. Proceeding exactly as in the hands-on investigation, guided by similar written material, students were shown on paper the content of the six boxes and were asked to find out what was in each one.

In an inquiry-based science programme, 100 sixth-grade students completed both assessments after a period of three weeks.
For both assessment methods the mean performance of students and individual student scores were compared. The mean performance for the computer simulation test was a little higher than that for the hands-on test. The score distribution for the computer simulation test was less broad than for the hands-on test. For example, none of the students scored zero and

almost twice as many students scored four out of six on the computer (N=25) than in the hands-on assessment (N=14).

Finally, given the desirable features of this technology, the research suggests a significant potential for computer simulations as a form of performance assessment. It is of importance that the format is inherently motivating to students who feel free to experiment with the technology while posing questions and looking for solutions. The simulation then serves not only as an instructional software tool but also as an assessment tool (Shavelson and Baxter 1992).

1.3 AN OUTLINE OF THE THESIS

1.3.1 THE CONTRIBUTION OF THE THESIS

1.3.1.a ACHIEVEMENT

The main contribution of this work is:

a) to provide a methodology for confronting science misconceptions or alternative frameworks;

b) to produce further evidence for the widespread nature of fundamental misconceptions or alternative frameworks;

c) to demonstrate that modelling provides some solutions to learning & teaching science subjects

d) to outline the ways which such work might be developed in order to provide powerful learning environments.

1.3.1.b IMPORTANCE OF THE TOPIC

For the learner

Students work in an interactive and exploratory learning environment. As users of this software, they develop:

a) independent learning based on the students' self-confidence because of the motivational environment and feedback provided by the software. They can work according to their own level, needs and requirements;

b) cognitive strategies;

c) imaginative, reasoning and other skills.

For the teacher

He/she has a remedial teaching tool, which has been designed for various levels of students' knowledge, and can help to identify the certain misconceptions or alternative frameworks of his/her students and provide more concrete assistance where it is needed. This means that in a first phase, students can help themselves by using the feedback provided by the software. Hence, the teacher's help is mainly focused on certain groups of students with particular difficulties. A more effective distribution of work takes place not only for the teacher but also for students. Consequently, a pleasant learning atmosphere and spirit are created for both factors of a classroom interaction.

For the designer

The results of the evaluation of the described software might be a framework for an integrated design of effective and educational software. Bearing in mind students' and teachers' needs and requirements and as a professional in this field, he/she can contribute a high level text, graphic and audio design.

1. 3. 2. THE STRUCTURE OF THE THESIS

The thesis is divided into five chapters.

The current chapter highlights the basic goals of the research and outlines its essential components, such as the importance of modelling activities, the need for computer-based modelling environments and the significance of the students' misconceptions for the design and the evaluation of the instructional software, with reference to work done by other researchers.

Chapter two explains the methodology used. This includes a discussion of:
a) The design of the software which is based on students' misconceptions or alternative frameworks on models of electrical concepts, and provides visible analogies of simple electrical phenomena which are in conflict with students' models so that they encourage students to question their model, and then extend and modify it;
b) The subjects: a sample of first year University students and their features;
c) The description of the software which is mainly a questions/exercise package followed by theoretical feedback and an evaluation of students' responses, both of which are provided by the software;
d) The procedure which provides a step-by-step description of what was done in the evaluation of the software in both human-computer interaction

(technical domain) and learning about electricity (subject domain) by using mainly tests (in three phases), questionnaires and supplementary information from observations and interviews.

Chapter three includes data which comes from:
a) The students' answers to ten multiple choice questions and their explanations;
b) The students' assessment of the use of a spreadsheet database and graphics capability;
c) The students' responses to the questionnaires.
The statistical analysis of the data and the results are simply presented.

Chapter four includes the quantitative and qualitative analysis of the data gathered and a detailed discussion regarding the impact of the instructional software on students' learning about electricity.

Chapter five presents the conclusions and recommendations of this research. There is evidence that the software facilitated teaching and learning of electrical concepts and that the design of such an interactive computational environment can motivate students' interest, despite its simplicity. The possibilities of providing high level text, graphics and audio design of these teaching packages are considered, along with recommendations for the future of such systems in the context of Artificial Intelligence research and Educational issues.

CHAPTER 2

METHODOLOGICAL ISSUES

This chapter describes firstly the main design principles of the "Learning electricity" instructional software. As a learning & teaching package, it is based on activating adequate strategies and techniques in order to improve students' understanding of electrical concepts and phenomena. Taking into account that learning is a conceptual change, the software is aimed to put into cognitive conflict the students' ideas and mental models with those of scientists' on the subject area. Research findings discussed in Chapter 1 prove that the use of modelling environments appears to be an effective approach to introduce abstract science concepts. Thus, within the framework of the use of HyperCard techniques and other multimedia systems, the presentation of concepts on the screen was in the form of models and analogies. The effective use of models and analogies was enjoyable as a method for solving problems in a such a difficult subject area and also correlated the unfamiliar abstract electrical concepts to the concrete ones. Hence the students had fun with electricity, as noted in their reports. The smart illustrations and animated pictures also introduced another way of reasoning which helped them understand these concepts and also consolidate their knowledge.

Secondly, information is provided concerning the selection of the subjects who were used for the evaluation of the instructional software for both human-computer interaction and for learning physics topics. The students' knowledge background in both domains was also taken into consideration.

Thirdly, the description of the "Learning electricity" instructional software follows in detail.

Finally, the methodology and the whole procedure for evaluating the software is presented.

2. 1 DESIGN

The main objectives for the "Learning Electricity" instructional software are :
1) Learning abstract electrical concepts;
2) Use of models and analogies for learning these concepts;

3) Use of HyperCard and other multimedia techniques for the presentation of these concepts on the screen .

The research interest focused on how to create "special designed remedial activities integrated into normal classroom activities, based on a pedagogical model which took into due consideration the students' preconceptions" (Picciarelli et al. 1991a) and to activate adequate strategies to improve their learning, so that students can overcome their difficulties. While using the software, which provides visible analogies and concrete visual models of electrical concepts within the framework of a versatile HyperCard and multimedia system, students are put into conflict with their model. They are then encouraged to question their model, extending and modifying it as necessary, so that learning takes place.

2. 1. 1 LEARNING

2. 1. 1. a The Constructivistic view of learning

Resnick (1983) pointed out that research in cognitive science has produced a new consensus on the nature of learning science which can help in understanding why alternative concepts occur.

Knowledge representation is unique to an individual and each learner generates his/her own links between old and new. Therefore, different learners build alternative viewpoints of the same phenomenon. This consensus, termed the constructivistic view, holds considerable promise for radical improvements in learning & teaching science.

On the one hand, learning can only happen by relating the unknown to what is already known and thus the whole process of learning depends on the learner's prior knowledge, serving as a "format" (or "schema") into which the new information is fitted (Rumelhart and Ortony 1977).

On the other hand, learning involves the active generation of links between new information and existing knowledge by the learner (Osborne and Wittrock (1983).

2. 1. 1 a 1) Learning as a conceptual change

The constructivistic view of learning was developed into the conceptual change model of learning by Posner et al. (1982) and Hewson (1981). From this viewpoint, learning involves an interaction between new and existing concepts which may be restructured or even exchanged.

2. 1. 1 a 2) Conditions of conceptual change

According to Posner et al (1982) the three following conditions are required before the learner can integrate the new concept with his/her existing knowledge:

1) "A new concept(ion) has to be intelligible"

The learner has to know what it means, has to be able to construct its coherent representation and has to see it as internally consistent. Although it is not necessary for him/her to believe it is true.

2) "A new concept(ion) has to be initially plausible"

The learner must not only know what it means but also believes that it is really true and consistent with his/her views. Therefore, the learner becomes reconciled with the new concept.

3) "A new concept(ion) has to be fruitful"

The new concept can broaden the learner's new areas of inquiry, suggests new approaches and ideas and can be extended. Therefore, it enables students to solve a problem they were previously unable to solve and to give a better explanation of concepts or phenomena. The new concept can be incorporated into the learner's schemata. Consequently, the latter can be rejected or restructured or exchanged.

A relationship between a new concept and the learner's schemata exists and determines which of the conditions are satisfied. This relationship is called learner's conceptual ecology which comprises various kinds of knowledge, such as analogies and metaphors, exemplars and images etc.

From the point of view of conceptual conflict, however, the most important constituents of learner's conceptual ecology are his/her epistemological commitments to such standards as "generalizability" and "internal consistency".

2. 1. 1 a 3) Learning as a cognitive conflict

The learner's conceptual understanding is an attempt to interpret observation and experience in terms of existing ideas and concepts. Experiences which generate conceptual conflict and dissatisfaction with existing schema are presented as a mechanism of adaptation and change in understanding (Driver 1986). Even then, it is argued that only if the idea presented is seen as being plausible, intelligible and fruitful, adaptation will occur (Hewson and Hewson 1984).

Thus, in the software evaluated topics students are required to choose one out of three answers or in some cases two out of five answers (multiple choice).

For most of the students the failure of their own ideas about the likely outcomes, to which they were committed, hopefully motivates them to re-examine their own concepts and assimilate the alternative theoretical explanations provided by the software/teacher (researcher). From a constructivistic perspective, such material provides a valuable means of generating conceptual conflict.

2. 1. 1 a 4) Conditions of cognitive conflict

"1) It is necessary that for the student both concept(ion)s are intelligible," otherwise there is no conflict.

"2) It is necessary that the student compares the two concept(ion)s and finds them to be in conflict. This requires the student to have, as a part of his/her conceptual ecology, some basis of comparison, and an epistemological commitment to internal consistency. These, however, are what are necessary for deciding the plausibility of either conception. In other words, a students' recognition that a conflict exists is equivalent to the recognition that, for him/her, only one of them can be plausible.

3) Finally, conflict can be resolved in two ways.

On the one hand, the student might choose to limit the extent of internal consistency. This leads to a compartmentalisation of his/her knowledge, with each concept(ion) being plausible within different knowledge subsets. This is equivalent to the student making the implicit assumption that there is no satisfactory basis for comparing the two concept(ion)s.

On the other hand, if a student has a strong epistemological commitment to generalizability, knowledge compartmentalisation may not be an option, in which case the outcome of the conflict will be acceptance of the concept(ion) which is plausible, and rejection of the other.

It is important to mention how essential the epistemological commitments are to conceptual conflict. Without such a commitment to internal consistency, the conflict will not lead to the rejection of an alternative concept(ion). The constituents of a student's conceptual ecology are critical determinants of any conceptual change which a student undergoes" (Hewson & Hewson 1984, p. 8).

2. 1. 1 a 5) Prerequisites for learning

Looking for factors which have an impact on learning should improve students' learning. According to fig. 2-1, learning depends on "studying activities" which in turn are dependent on five factors:

1) Prior knowledge;
2) Intellectual capability;
3) Environmental factors;

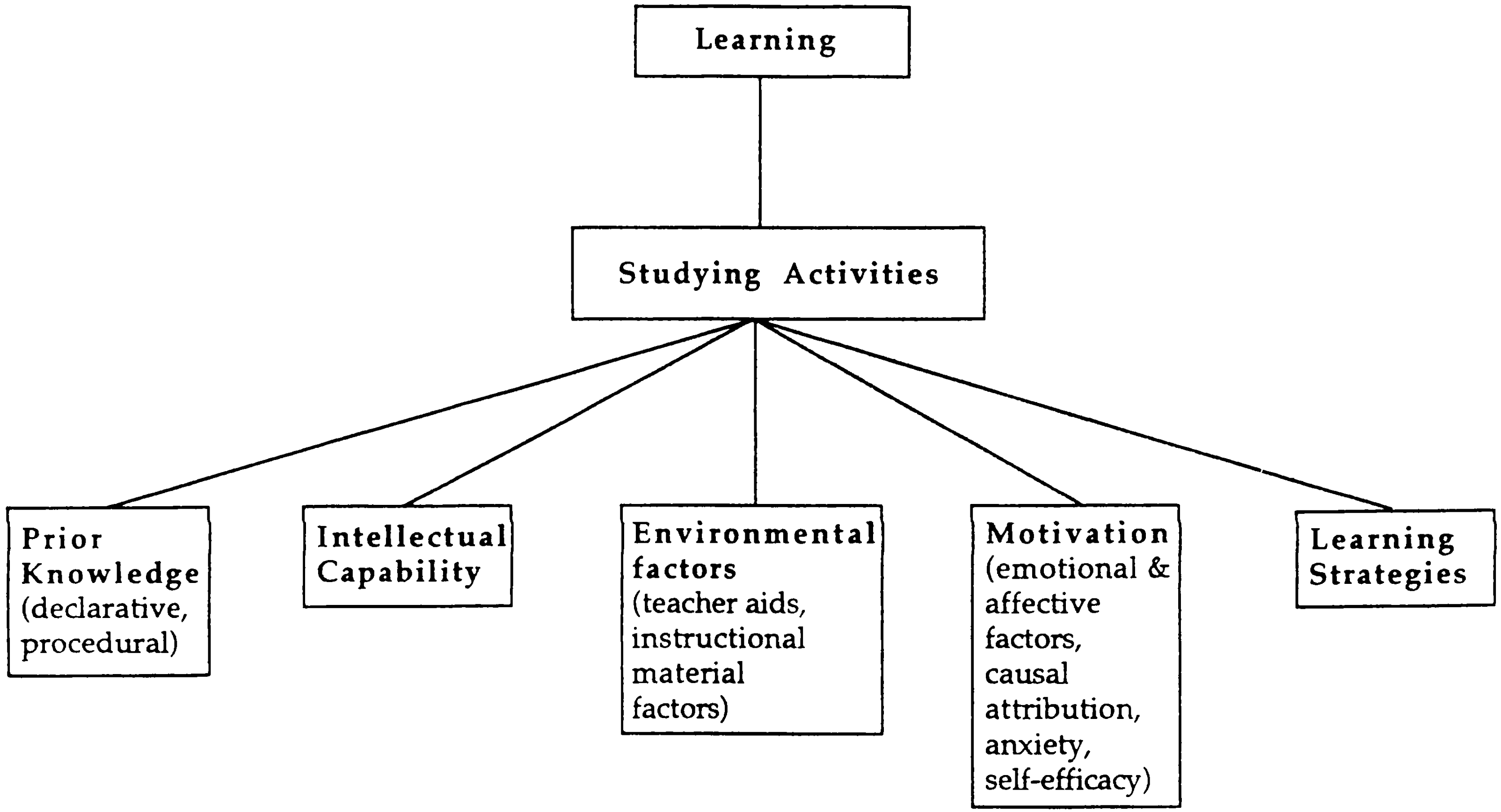


Figure 2-1
Prerequisites of learning
[from Klauer, K. J. (1988) p. 354]

4) Motivation;

5) Learning strategies.

These are not independent of each other but instead are interwoven.

Concerning the prior knowledge, there is a detailed discussion on students' misconceptions or alternative frameworks on models of electrical concepts in Chapter 1. The other factors, such as intellectual capability, environmental factors, motivation and learning strategies are analysed in sections 2. 1. 1 b, 2. 1. 1. c, 2. 1. 1. d, 2. 1. 3 and 2. 2 of this Chapter, respectively.

2. 1. 1 b Teaching & learning strategies

According to Posner et al. (1982), the following teaching & learning strategies are necessary for the effective teaching & learning of science. These are:

<u>Diagnosis</u>

When a concept is intelligible, plausible and fruitful to one student, it may not necessarily be so to another. Students' existing knowledge needs to be taken into account. Diagnosis therefore is an indispensable prerequisite for any teaching & learning strategy. While using the software and checking their answers, students diagnose their errors in their understanding of electrical concepts.

<u>Integration</u>

When two different concepts are reconcilable with each other, but are not linked, integration is the appropriate teaching & learning strategy. This could involve the integration of a new concept with a student's existing concept, or of existing different ones. It is important to note that there is no conflict between the two reconcilable concepts from either the teacher's or the student's viewpoints. While using this software, which provides the diagnosis of their errors in understanding of some concepts, students are encouraged to question their model, extending and modifying it. This happens in concepts such as electric current, resistance, potential difference (pd.).

<u>Differentiation</u>

Many science concepts are different, but closely related. Students are frequently confused by these kinds of concepts and hold a single undifferentiated concept, which is possibly based on too limited a range of examples. The appropriate teaching & learning strategy in such a case is the differentiation of these two concepts. Therefore, there is no possibility of conceptual conflict, since they are possibly reconcilable.

For example, the concepts of voltage or potential difference (pd.) and electric current are closely related. The software clearly differentiates between the cause of the electric current (electron flow), i.e. the potential difference (pd.), and the result of the existence of the potential difference (pd.), i.e. the electric current (electron flow), between the ends of a wire. Thus, one of the software goals is for students to become "voltage-minded" rather than "current-minded". In other words, potential difference represents the cause of the free electron movement. Consequently, if there is no potential difference, the electric current does not flow.

Exchange

When two different concepts are irreconcilable with each other, and are seen to be so by a student, then the new concept could be either rejected, or restructured and exchanged with the old one.

Rejection is likely to occur if the teacher does not use an explicit exchange strategy. A rejection strategy reduces the plausibility of the old concept and increases the plausibility of the new one. In other words, an exchange strategy aims to create conceptual conflict between a student's concepts, and then resolve it appropriately.

For example, the fact that the electric current is a flow of energy and not a flow of charge is the final step of an upward movement in the teaching & learning process included in the software design. The software is based on the moving crowd model which starts with an introduction of this concept. Finally, the "snapping marbles" model gives a more complete understanding of electric current. Thus, students easily explain why the light turns on immediately when the switch is closed. It is analogous to snapping marbles because electric current is a transference of energy from the first electron to the last one of the row in a copper wire. Actually energy is transferred immediately and the bulb is on at the same time.

All the above mentioned strategies are analysed in detail later in Chapter 4, in which a discussion on the results of the evaluation of the software is included.

2. 1. 1 b 1) Instructional implications : The role of teacher / software

Teaching is typically considered as a clarification of texts which provide solutions to problems and laboratory exercises, also a test for understanding and an ability to apply the material taught. In this research, this approach of teaching/learning is targeted at recall, assimilation and accommodation of knowledge. Therefore, it adjusts the following strategies, as proposed by Posner et al. (1982, p. p. 225-226):

1) Development of questions which "can be used to create cognitive conflicts in students is necessary as preparation for an accommodation (Stavy and Berkowitz, 1980)".

2) Organisation of instruction "so that researcher/teacher can diagnose errors in students' thinking and can spend a substantial time in identifying defensive moves used by students to resist accommodation".
3) Development of the strategies "which the researcher/teacher could include in their repertoire to deal with student errors and moves to interfere with accommodation".
4) Help for the students to "make sense of science content by representing content in multiple modes (e.g. verbal, mathematical, concrete-practical, pictorial) and by helping students to translate from one mode of representation to another (Clement 1977)".
5) Development of evaluation techniques to enable "the teacher and students to track the process of their conceptual change".

With regard to the teacher/software role, the teacher/software as "clarifier of ideas" and "presenter of information" is clearly not adequate for helping students to recall, assimilate and accommodate new concepts. This particular research suggests that the researcher/teacher might have to assume two further roles in order to facilitate student's recall, assimilation and accommodation. In addition to these roles, the teacher/software would become:
"1) An adversary in the sense of a Socratic tutor;
The teacher/software confronts the students with a problem arising from their attempts to assimilate new concept(ion)s. A point of concern is the need to avoid establishing an adversial role with regard to students as persons while developing and maintaining it with regard to concept(ion)s.
2) A model of scientific thinking;
Aspects of such a model might include a ruthless demand of consistency among beliefs, scepticism for excessive "ad hoc-ness" in theories and a critical appreciation of whether discrepancies between results may be "reasonable agreement" with theory (Kuhn 1970)" (Posner et al. 1982, p. 226).

Although the work in the area of encouraging and producing conceptual change is almost twelve years old, little seems to have been done beyond distilling the results into a few principles. As mentioned, Dykstra et al. (1992) describe certain steps learners go through during conceptual change with which many would agree on. They have identified important aspects of conceptual change:

1) becoming dissatisfied with a concept;
2) exploring plausible alternatives;
3) choosing a fruitful one.

Based on constructivistic beliefs about learning, the teacher acts as "provocateur" and "facilitator", rather than "transmitter of knowledge". The next section presents more details of specific applications of this strategy.

2. 1. 1 b 2) A taxonomy of conceptual change

In this particular thesis, the researcher's initial thinking on the issue of strategies for conceptual change suggests that it is possible to organise examples of conceptual change into a taxonomy. This is a taxonomy of conceptual change, which can not possibly be hierarchical and is not the same as a taxonomy of concepts. In this instance, the categories are characterised by:

* important changes in the representation of knowledge (concepts) from before to after conceptual change;

* important features of the strategies which encourage and produce the type of conceptual change represented by the categories.

Based on this particular research and experience with the students working with the software, the researcher agrees with Dykstra et al. (1992, p. 637) who identified three strategies of conceptual change :

1)"Differentiation, wherein new concepts emerge from existing, more general concepts", for example intensity and resistance emerging from generic ideas of motion within teaching/learning about electricity

2) "Class extension, wherein existing concepts considered different are found to be cases of one subsuming concept", for example current and electricity coming to be viewed as equivalent.

3) "Reconceptualization, wherein a significant change in the nature and relationship between concepts occurs", for example in the change from "current is used up" to "current is conserved".

This taxonomy would enable teachers to probe the nature of conceptual change in depth and could be used by them to assist their students' decision making.

From data of this research, the students show the above mentioned conceptual change processes:

Differentiation

Differentiation is a constituent of the conceptual change taxonomy. For example in this particular research, differentiation between electric current and electrical energy from the less specific concept of electricity. While researchers, such as Osborne (1985) and Picciarelli et al (1991), refer to students' ideas of electric current, some students do not refer to current but refer to electricity. The researcher is not inclined, therefore, to consider their predictions of the behaviour of electrical circuits to be indicative of conceptions about electric current because current is not a distinguishable entity for them (Dykstra et al. 1992). Since their primary experiences with electricity deal with electrical energy, their predictions about electrical phenomena seem to be based on concepts of something that is energy-like e.g. electricity (not electric current) which is "used up" as it passes around a circuit, i.e. that less gets back to the battery than leaves the battery. The researcher's instructional goal is for students to begin to "see" electricity as having features of both something which "flows" in the circuit, which is not "used up" (electric current) and something which is "used up" (electrical energy) (Joshua and Dupin 1985).

Class extension

Class extension is another constituent of this taxonomy. For instance, studying current through the "Current in wires" stack, students do not see it as an energy flow. Students debate as to whether it is correct to consider current as a flow of electrons inside a conductor. A difference of opinion over what is necessary so as to explain the phenomenon is required to get the debate started. In this setting some students undergo conceptual change, which includes reclassification of their views.

Reconceptualization

Reconceptualization is also a constituent of taxonomy and usually occurs when existing explanations are found to be inadequate. Such changes in students' reasoning are similar to changes in the reasoning of scientists. This kind of change is more profound and difficult. It includes the shift from thinking about electric current in the sequential model, which students possess, to a scientific model of current. In the research, this profound change is represented by a change in abstract category (from "attribute" to "relation") of an important concept (electric current) and in its proportional relationship (causes) to other entities (pd. and resistance). This kind of shift represent a significant conceptual change in the nature of the electric current.

2. 1. 1 c Environmental factors and learning

2. 1. 1 c 1) Visual learning

Images (as icons or pictures) are visual symbols for entities or actions and can be used to powerfully represent information. Their role in human communication is sometimes difficult to determine. Human memory can be viewed as consisting of three types: long-term memory, short-term memory and external memory (Simon and Newell 1972). The external memory may come in the form of a computer graphics screen. Psychological research suggests that individual differences in cognitive style significantly affect the way in which a picture/graphics screen can help a problem-solver.

Pictures and learning

Learning can generally be accomplished through the use of techniques which solidifies what is to be learned. So, teachers' chosen methods and materials, which capitalise on students' previous encounters with their environments and which provide a closer approximation to those environments, can be provided through abstract representations.

In particular, the researcher's efforts toward concretization involved pictures, both as learning materials and as the principal ingredient in the students' initiation into cognitive strategies.

Source books confirmed that pictorially presented objects are more memorable than their associated verbal labels. In many studies (Levin and Allen 1976), the provision of "pictures along with the orally presented passage substantially improved the students' performance". This has been noted, not only for simple learning tasks, but also for more complex ones. In particular, visual imagery facilitates associative learning. The ability to generate effective organisations of images appears to be closely related to the cognitive level of a learner. However, even young learners, below the required cognitive level, may be induced to generate imagery by means of appropriate training, tutorials and activities.

Imagery

According to White (1990, p. 5), "the term imagery is used here to encompass two forms of visualisation:

a) the external forms, such as painting, sculpture, woodcuts, engraving and mosaics, as well as the contemporary forms of film, television, computer graphics and video and

b) the internal forms of mental pictures employed in imagination, in thinking and in memory".

For the first time in psychology, Aristotle's theory stressed that "the soul never thinks without a mental picture". Nevertheless, for centuries this view was hidden behind the belief of "imageless thought". In the twentieth century, the psychology of learning has dealt mostly with learning of words and numbers and very little with imagery learning. The lack of research in imagery learning comes from the fact that human learning has moved from print back to imagery in this last century. Over the past four centuries, this movement was almost unnoticed in learning theories. Due to the logocentric approach to the study of human learning, imagery is underestimated and considered to play "a role secondary and ancillary to word learning". Thus, there is no real understanding of "how imagery works in human mental operations" (White, 1990, p. 7).

Recently technological inventions have had a great impact on human reasoning and imagination. In this century, imagery has been largely identified with entertainment, not with learning. One of the things that imagery does best is to help people remember. The view of teaching languages through ordered pictures was truly original, and was followed by the view of teaching in other domains. Research (White 1990, p. 7) proves that "imagery has remained an important tool for recording scientific reality. Its use moved from schematic drawings to detailed drawings printed in textbooks, to using photographs as scientific evidence. Also thinking in images has been a great help to scientific thinking and it is a creative tool for scientific discoveries..... Almost all of science is today highly dependant upon imaging technology as a major scientific exploratory tool".

Also White (1990, p. 7) notes six features of imagery:

" 1) Imagery models (illustrates) human behaviour, inducing imitation;

2) Imagery adds drama to a presentation;

3) Imagery invokes a range of emotional responses, possibly more than other media;

4) Imagery maintains attention possibly more than other media;

5) Imagery is easily remembered, possibly more than other media;

6) Imagery can widen the visual context of material presented"

In addition, these are found to be critical to human learning. Imagery therefore can be considered as a mental tool with great impact on human learning.

Analogical imagery

This term is used for the internal forms of mental pictures where models and analogies are included. There is a detailed discussion in section 2. 1. 2 on "Metaphorical thinking"

2. 1. 1 c 2) Learning with computers

The interaction between teachers, students, computers, and their surrounding environment is important for teaching & learning. As Papert (1987) pointed out, the computer is only one of the components in a computer learning culture. Taking into account, teaching is the provision of the kinds of environments where students can use a computer as a tool to enhance their cognitive self-management skills. The main goal of the use of computers is to teach students to become active and purposeful thinkers, learners and problem solvers. However, it is essential that the teaching of thinking and learning strategies takes place within the context of a learning environment and not in isolation from the real world. Thus, students reflect on their thinking within various areas of the school programme and their lives. The development of thinking skills is not only important for academic development but also for growth in social skills and emotional adjustment.

Ryba and Anderson (1990, p. 1) claimed that there are two major perspectives in the learning process:
"a) The Behavioural Perspective, which emphasises the role of the environment in learning and instruction. The main aim is to understand how certain conditions in the learner's environment affect the quality and quantity of learning. The focus is on directly observing conditions external to the individual learner.
b) The Cognitive Perspective, which emphasises events and processes which take place within the individual learner. This involves the study of a number of mental processes involved in receiving, storing, processing, retrieving and applying information. The active role of the individual learner, rather than the environment, is considered to be the main determinant of learning".

Thinking skills and strategies

According to Alley and Deshler (1979), thinking is a process involving collection, manipulation and the use of information to solve problems.
Certain skills (Table 2-1) have been identified by various researchers as relating to important internal processes, which form the basis for the development of cognitive strategies and are internally organised skills or control processes by which learners regulate their cognitive behaviour (Gagne 1977).
Thinking skills and strategies are tools which help students to acquire, retain and apply new information more effectively and efficiently.

Metacognitive skills and strategies

Metacognition is one's ability to be aware of his/her thinking processes or "the awareness of oneself as an active agent in the process of knowing" (Spiro et al. 1980).
Papert (1980) claimed that students, who show the metacognitive skills listed in Table 2-2, are aware of their own thinking and make conscious attempts to.

Thinking Skills

A. Exploration

observing
describing
predicting and explaining
comparing and contrasting

B. Analysis and Planning

identifying the problem
analysing the problem
developing options for problem-solving and decision making

C. Questioning

knowing how and when to ask questions
asking different kind of questions

D. Self-monitoring

checking and regulating activities
evaluating and revising activities

Table 2-1

Thinking skills and strategies

[From Ryba,K. and Anderson, B. (1990) p. 2]

The Main Types of Metacognitive Skills

1. Self-evaluation	6. Checking
2. Reflection	7. Prediction
3. Thinking about thinking	8. Monitoring
4. Analysis and planning	9. Reality testing
5. Self-regulation	

Table 2-2

Metacognitive skills and strategies

[From Ryba, K. and Anderson, B. (1990) p. 2] control their problem solving strategies. This is in agreement with Piaget's view concerning advanced thinking (Piaget and Inhelder 1969). Vygotsky (1978) stresses that social interactions with learners are essential factors to develop metacognition and awareness of self-regulatory activities.

There has been speculation that computers can be used to support the development of metacognitive skills. This is because many computer applications are useful for student-centred activities, such as checking, planning, predicting, comparing, analysing, exploring, evaluating and monitoring.

2. 1. 1 c 3) Computers and development of thinking skills

The educational value of computers cannot simply be measured by the content of the software. It is the process of teaching & learning that the software employs that largely determines its value.

Attention is being given to the process of helping students to "learn how to learn". The essential aim is to assist them into acquire some personal skills which are required to be more effective in academic work and daily life.

From the National Curriculum on I.T., these skills are:

Thinking - skills of acquiring knowledge, reflection and evaluation, logical organisation and presentation of thought, associating, reasoning and creative use of intuition, analysis and problem-solving.

Expressing - skills of creating and expressing ideas and responding to the ideas of others in a variety of forms and styles.

Relating to others - skills of relating to other people's way of life and the contributions made by different cultures and individuals.

Carrying out practical activities and studies - skills for learning through carrying out practical tasks and applying creative ideas to solve practical problems.

2. 1. 1 c 4) Computers and conceptual change

From a Piagetian perspective, I. T. provides a graphic and first-hand illustration of some of the abstract science models and ideas. Additionally, because of the accuracy and flexibility of technology, it encourages scientific investigation rather than the confirmation of theory. Such work stimulates students to apply hypothetico-deductive thinking to genuine problems which is normally only achieved by a fraction of the population (30%) at age of 16 and over.

From a constructivistic perspective, the computer interface offers experiences which challenge common misconceptions held by students. They are encouraged to predict and interpret the outcomes in terms of their prior conceptions. Failure to correctly anticipate and/or explain the behaviour of

the system confronts their ideas. Such experiences are proposed by Hewson (1981), Driver and Oldham (1986) and Rowell et al. (1990).
Even those who emphasise the importance of language and context find that computers have a major contribution to teaching & learning science because they enable the teacher to "bring to life ideas that would otherwise be confined to words on paper" (Solomon 1988). Clearly, from such a perspective, it is essential to provide images to illustrate phenomena and particular ones that are clear, tangible and immediate. Computer interfaces serve both functions by illustrating a wide range of phenomena and by providing these immediately. Additionally, students' trust in the authority of a computer acts as a stimulus to the serious consideration of their work and of the meanings of their teacher.
Finally, computer technology enables new approaches by using various media - such as slide projector, film projector, video recorder and other audio visual equipment - and so it provides access to a wide range of experiences which have changed and improved the nature of science teaching & learning.

2. 1. 1 c 5) Computers : Exploratory learning environments
As Driver (1983) points out "If we wish students to develop an understanding of the conventional concepts and principles of science, more is required than simply providing practical experiences. The theoretical models and scientific conventions will not be 'discovered' by students through their practical work. They need to be presented. Guidance is then needed to help children to assimilate their (practical) experiences into what is possibly a new way of thinking about them". Students need guidance and opportunities to explore scientific ideas, concepts and representations, confronting them with their prior ideas. Exploring scientific ideas is something very different from just being told. When students explore ideas they can get a profound insight into the ideas they are exploring. Exploring is a way to build support for the not so obvious models that scientists use.

Learning in a computer-based exploratory environment such as the "Learning Electricity" software requires cognitive and metacognitive skills from students. Cognitive skills are required in the sense that students must act to manipulate and integrate information. Metacognition skills are required in the sense that students must regulate and control their actions and knowledge in order to build new knowledge.
The "Learning Electricity" software, as an exploratory environment, can only be of some use if a student devises and evaluates strategies. For example, to investigate the effect of current flow, potential difference and resistance

students must explore the relevant stacks in the software by activating animated pictures and see their effects over the whole circuit.
Acting, verbalising, controlling, predicting, devising strategy, evaluating, confronting are some of the cognitive and metacognitive processes that students must develop and use to construct their knowledge with the software.

2. 1. 1 d Motivation and learning

"No compulsory learning can remain in the soul... In teaching children, train them by a kind of game, and you will be able to see more clearly the natural bent of each." (Plato, The Republic, Book VII)
Motivation is a practical problem, especially in science instructional design. One potentially overpowering factor which has largely been neglected is the role of motivation in learning. This role figured prominently in the historical development of psychology (Thorndike 1911, Hull 1943, Skinner 1953). There are some reasons to believe that given sufficient motivation and even moderately informative environments, most students could learn the greater part most of what they are taught. According to Cremin (1961), motivation has been a foremost problem in education, especially in the last half of this century. Extensive psychological literature exists about the motivational effects of various kinds of reinforcement and of various kinds of modelling (Skinner 1953, Bandura 1969).

Cognitively oriented learning theorists (Piaget 1951 & 1971, Bruner 1962) argue the importance of intrinsically motivated play-like activities for kinds of deeper learning. Thus, motivation is of importance to science instructional design. If students are intrinsically motivated to learn something they are likely to spend more time and effort on learning, feel better about what they learn, and be more likely to use it in the future. Some theorists would also argue that students learn "better" in the sense that the more essential cognitive structures are modified, including the development of such skills as "how to learn" (Shulman and Keislar 1966).

As an instructional designer, the researcher's task is to create settings where students are motivated to learn as efficiently and enjoyably as possible, by creating intrinsically motivating environments. Parker and Lepper (1992), who focused mainly on learners' play, claim that the features of intrinsically motivating environments are:

Challenge

This kind of motivation leads learners to develop competence and feelings of efficacy in dealing with their environment.

Fantasy

Piaget (1969 & 1971) emphasises the predominance of "assimilation" to existing structures in a learner-determined play with minimal needs to "accommodate" to an external reality.

Curiosity

Curiosity is analysed into novelty, complexity, surprisingness and incongruity.

According to Berlyne (1966), the principal factor producing curiosity is what is called conceptual conflict; that means conflict between incompatible attitudes or ideas evoked by a stimulus situation. In essence, Berlyne's "conceptual conflict" would be called a "lack of consistency" (or "lack of completeness"). Concerning the subject "Motivation and Learning" within a human-computer interaction, further details are given later, in the section 2. 1. 3.

2. 1. 2 METAPHORICAL THINKING

Maxwell based his equations of electromagnetic fields on a visual model involving lines of forces, tubes, surfaces and moving fluids, to which he applied the mathematics appropriate to such fluids. Later, however, he dropped this imagery preferring the mathematics to stand alone, commenting only that :

> "For the sake of persons of different types of mind,
> scientific truth should be presented in different forms
> and should be regarded as equally scientific whether
> it appears in the robust form and vivid colouring of
> a physical illustration or in the tenacity and paleness
> of a symbolical expression" (Koestler 1969, p. 424)

How do people select words and expressions to describe their novel insights? Why did Kepler choose the word "focus" to describe the place around which the movement of planets "centres"? Why did Robert Hooke describe what he saw down the microscope as a system of "cells" (previously defined as rooms for monks in a monastery, and, by extension, any compartments)? Why did the physicists and engineers talk of "harnessing" the energy of water at the same time as they were inventing the "horsepower" as a unit of measuring rates of working? And what "stroke" or flash of insight made biochemists speak of a certain kind of substance as a "messenger" ribonucleic acid?

Most people would probably consider the study of metaphorical language as a branch of literary studies and so it comes as a surprise to find that interest in its influence on scientific reasoning has grown substantially in the last twenty years. Metaphors (using the word in its widest sense, to include similes, personifications, analogies, models and other figurative speech) is not just "a decorative device to assist communication but an epistemological necessity". Their role in the creation of knowledge is powerful because they were found at several serious points in the intellectual development of both individuals and societies, such as:
a) in scientific theorising
b) in the evolution of language
c) in students' attempts to interpret new experience and
d) in teachers' efforts to help students to interpret new experiences.

2. 1. 2 a Explanation of the terms

The following terms are words which are not mutually exclusive, nor are they closely defined; they shade off into one another in meaning.

Similes

Similes are simply comparisons between two things. The comparison is made just to find some way of understanding the new information in terms of what is already familiar and there is no close examination of the detail of how the compared things are similar.

Analogies

According to Gentner (1982), Green (1971), Curtis and Reigeluth (1984) analogy is an explicit, non-literal comparison between two things in which their structural, functional and/or causal similarities, and often their differences, are described. Under this consideration, analogies are extended similes, in which an attempt is made to trace multiple points of comparison towards a more precise understanding of the original new information.
The value of an analogy, as a means to understanding the original, lies both in the attempt to make more cross-connections and in the inspection process which examines their validity. A result of this is that the user-learner conceptualises shared qualities which were previously unnoticed and delineates properties which are really specific to the system which is under examination.

Metaphors

In comparison to analogies, metaphors are firstly less explicit and much more mentally teasing. In various subjects words are usually borrowed from a greater distance, as it were, and the metaphorical effect is more dramatic on the first use. For example, consider the idea of a political "arena" or "theatre" of war in strategic studies. When a really successful metaphor is taken up and used over and over again, the meaning of the word (or words) is nearly always enlarged and the impact of the metaphor correspondingly diminishes. Thus, the name "spectrometer" for a device separating different kinds of light is broadened to include a device which separates particles of different mass, the "mass-spectrometer". Mental acceptance is so rapid and complete that the origins of the usage are forgotten and seems just as natural to use the word in the new way.

It is a marked feature of metaphors that they become elaborated into models. Firstly, they so excite the mind in the exploration of implications that they yield great feelings of "insight", but later on they come to look like literal descriptions of reality.

Models

A model can be considered as an extended metaphor, which firstly teases the mind and later is able to look like being very real. Thus, the two ideas or concepts stand together and the inventor explores implications. If any of these implications make contact with information already known, then the user-learner may start to schematise the model, substituting aspects of it for those aspects of the original idea or concept which seem to him/her to be most significant. The model then appears to show what is going on. The user-learner enters into the model imaginatively and with its help "sees" the idea or concept anew. Recent research claims that models gain credibility because people are convinced of their reality.

INTERACTIONS IN THOUGHT

increasing elaboration ↓	SIMILE →	METAPHOR →	PERSONIFICATION
	↓	↓	↓
	ANALOGY →	MODEL →	ANTHROPOMORPHISM

Figure 2-2

Interactions in thought

(transformed from Sutton, C. (1978, p. 8)

Personification
This term means treating something which is without life as a human being or representing it in human form. It can be considered as an extended metaphor because it can excite the mind for exploration and is capable of seeming human. Through its help, the user-learner is capable to "see" the concept/idea anew. Personification becomes elaborated into anthropomorphism.

Anthropomorphism
This term means a treatment of things or events as human in form and personality. It can be considered as an extended model firstly teasing and later appearing as a human being. Finally, it enables the user-learner to "see" it as not only reasonable but also real.

All the above mentioned terms seem to have a relationship to each other (Fig. 2-2). They differ in the degree of elaboration and explicitness with which the contact points are identified. They all have some capacity to tease the mind into exploration of future implications and also have some tendency to persuade their users that they have got hold of the "real thing".

From here onwards, it is convenient to use the word "metaphor" as a shorthand expression of "metaphorical thinking", covering all the other terms.

2. 1. 2 b Conceptualisation of human learning and memory

In any learning situation, the main task is to help learners to add to their existing knowledge and move from the known to the unknown. Thus, instruction mainly involves the search of the most effective, efficient and appealing way for this to be accomplished. A theory of instruction consists of certain interrelated statements, which explain and predict how information should be presented to support and enhance learning. The following three essential components were suggested by Resnick (1983):
1) An instructional theory should describe the processes through which learners can acquire new information.
2) An instructional theory should specify the desired outcomes.
3) An instructional theory should include principles of intervention, or what the instructor is to do and how that interacts with individual's learning processes to produce new learning.

2. 1. 2 b 1) Information processing theory of learning

Both memory, as an information processing system, and the conceptualisation of human learning provide a useful context in which to consider how metaphors work to facilitate the acquisition of new knowledge. The conceptualisation mainly focuses on the prior knowledge which is organised and stored in the learner's memory. According to Ausubel (1960), Ausubel, Novak and Hanesian (1978) and Glass and Holyoak (1986) previous knowledge serves as a framework or "assimilative context" (Mayer 1980) for the acquisition of new knowledge. Then, the old knowledge acts as a mediator for the acquisition of the new knowledge.

One of the essential tenets of the mediational view of learning proposes that all knowledge is stored in human memory in terms of interacting cognitive structures. These structures were entitled as: schemata (Rumelhart and Ortony 1977, Thorndyke and Hayes-Roth 1979), knowledge modules (Norman 1978), propositions (Anderson 1980), frames (Minsky 1975), and scripts (Abbot, Black and Smith 1985, Schank and Ableson 1977).

As a knowledge structure, a schema represents a concept in human memory (Rumelhart 1977) and includes in its representation the inter-relationships among the various aspects of the concept (Thorndyke and Hayes-Roth 1979). A learner's particular experiences cause the creation of these inter-relationships. These reproduce and express features which regularly occur to be abstracted from learner's similar experiences (Mandler 1985, Thorndyke and Hayes-Roth 1979). All kinds of concepts such as objects, situations, sequences of actions and events (Rumelhart and Ortony 1977) are represented as schemata and these provide a framework within which subsequent related information is organised mainly by interaction and perception (Norman 1978, Gentner and Stevens 1976).

The active discovery, the development of inter-relationships among pieces of knowledge and the interaction of new knowledge with old one, which exists as cognitive structures, are necessary prerequisites for the knowledge acquisition (Mayer 1979, 1980, Wittrock 1979). Therefore, when new knowledge is not related to or placed within existing cognitive structures this acquisition is probably hindered. At this point, the fact that metaphors enable learners to relate new unfamiliar knowledge to the familiar existing structures of knowledge, prove to be supportive in the process of learning.

a) Encoding of new knowledge

In their article, Stepich and Newby (1988, p. 132) introduced Rumelhart's (1977) view of human memory; in which the operation of memory is similar to a library's operation.

Both library and memory are used for the storage of large amounts of information. In both cases, it is required for the storage to be organised in such a way that easy access and use are facilitated. Therefore, new information is received and is located within an existing organisational framework, the Library's Dewey Decimal System. The locations are in close proximity to information from similar content areas.

Encoding into human memory follows a similar process. Senses are responsible for the delivery of new information. After being taken in new information is carefully thought about by existing knowledge. In learner's memory, there are networks of existing schemata (knowledge). Consequently there are locations where new information can be placed since it is adapted beyond others.

A metaphor/analogy enables the learner to use already existing knowledge to manipulate new information. As a result of that, effective encoding of new knowledge is facilitated. A metaphor/analogy activates the process of selecting a schema already known to the learner, who uses it as a pilot to construct another schema for the information to be acquired (Gick and Holyoak 1983, Rumelhart and Norman 1981).

According to Rumelhart and Norman (1981) this process enables the learner:

* to establish an "as like" relationship between same or similar structural, functional or causal features of two schemata and to link the new information with the existing knowledge;

* to focus on the most relevant aspects of the new information

* to synthesise them into a single integrated schema in which further details can be incorporated. Furthermore this schema can be more easily stored in the learner's memory than can the collection of its parts (Newby and Stepich 1987).

Consequently, a metaphor/analogy enables the learner to generate a schema for the new knowledge, using a schema of the existing knowledge.

As an example, consider the following metaphor/analogy: A resistor is like a hosepipe in that both oppose flow, the flow of electrons in the first case and the flow of water in the second case. This metaphor/analogy begins by focusing the learner's attention on the ability (function) of a resistor to reduce the strength of a current and linking it, based on their functional similarity, with the more familiar term, the hosepipe. The existing schema of prior knowledge (the hosepipe) provides a guide for the formation of a schema for the new information (resistor). The newly created schema provides a framework within which further new information can be understood. As information is obtained, for example, about how exactly a resistor opposes the flow of electrons and so reduces the size of the current this information can be integrated into the new "resistor" schema which was modelled on the schema for a hosepipe. Another example is the metaphor of electric current in the model of snapping one marble against one end of a row of marbles. Students can see how when the marble collides with the first marble of the row, it stops, transferring its energy along the row of marbles to the last marble of the row.

b) Retrieval of stored knowledge

As mentioned previously, memory consists of networks of existing schemata /knowledge. Information can be obtained from memory and provided for use. According to Stepitch and Newsby (1988, p. p. 133-134) this process is defined as retrieval of stored knowledge.

As Klatzky (1984) mentioned the retrieval process consists of the steps:

1) producing a retrieval cue;
2) looking through to find the contents of memory;
3) matching the stored knowledge against the initial cue;
4) providing a response.

Retrieval in a library means that the Library's Dewey Decimal System is used so that the location of a relevant book can be found. The library's card catalogue provides certain cues so that the place where the book is stored can be located. If the book provides the required information then it is taken and used. Otherwise, if the cues guide to a book, in which all relevant information may not been included, then additional materials within the same general subject area are often examined. Therefore all of the required information is brought together .

Similarly to a library, retrieval from memory also implies the use of the established encoding system (retrieval cue) for relevant information to be placed, matched against the need (initial cue) and used (Rumelhart 1977).

Often the learning environment provides the exact cues used to locate the relevant schema in the learner's memory. If a schema is found, then it is matched against the initial need of information. If it suits, it is used. Otherwise, if it is not suited then additional materials within the same general subject area are accessed and examined, as in the case of a library mentioned above.

In addition to the above, the acquisition of information stored in memory often implies rebuilding an integrated schematic network. This comes from the distillation of knowledge stored into memory (Rumelhart 1977, Anderson 1980, Mandler 1985). A small bit of information can start the rebuilding, which is self-generated. Certain details, examples and inferences are gradually added to the general knowledge along with specific information until a network of interrelated information has been reconstructed (Ortony 1975). As specific details are recalled they raise the recollection of additional information. This process continues until the desired knowledge has been recalled.

In a library a book should be easily found in the library's card catalogue and the card catalogue should clearly specify where this book is stored. In memory Rumelhart (1977) stressed on the importance of the effectiveness of the retrieval cue to find and use stored information.

The use of a metaphor/analogy helps out with the efficient retrieval of information from memory because it provides an efficient way to locate relevant information within the network of related schemata stored in the learner's memory (an effective retrieval cue). A memorable image along with other associated pieces of information can be used to begin the reconstruction of recall. Recalling the metaphor/analogy guides recalling the "is like" relationship existing between the new and old information stored in memory. This raises recalling more aspects of the new information and so on until the desired amount of detail has been recalled.

For example, information about resistance can be retrieved using the metaphor encoded into memory that a resistor is like a hosepipe. Recalling the representational image, "hosepipe", leads to recalling the "is like" relationship between a hosepipe and a resistor. Using the metaphor then leads to recalling how a hosepipe and a resistor are alike. This, in turn, raises the recall of various aspects of the schema for resistance, which continues until enough information about resistance has been retrieved, i. e. relationships between resistance and length, cross-section or temperature of wire.

2. 1. 2 b2) Metaphors : From Ausubel's viewpoint of learning

The creation of metaphors seems to be "another kind of pattern-seeking" and another strategy in the mental struggle to form an understanding of a new concept. Learners study the new and unknown knowledge, by scanning it over and over, until they can express it in terms of the old and known one. A

suitable metaphor, which fits the data somewhere, enables learners to add more data around it. This is what Ausubel calls an "organiser" which helps learners to relate different parts of the data to each other and to the understanding of the concept, so that learning is meaningful. This is a new way of looking at things.
There are many ways of placing of the familiar and old concept - which is called the "vehicle" according to Ortony (1979), Verbrugge and McCarrell (1977) - in the relationship to the new concept - which is called the "topic". Thus:
Acting as an analogical "advanced organiser" (Ausubel and Robinson 1969), the metaphor is presented at the beginning of the instruction, and provides the background information necessary for learning the new, unfamiliar concept (Hayes and Tierney 1980) and enables the learner to think back to the metaphor at various points in the instruction. Acting as an "embedded activator" (Reigeluth 1983a, Rigney 1978), the familiar concept is presented somewhere during the instruction; where the content is becoming most abstract and difficult the learner can use the metaphor cognitive strategy to facilitate his/her learning.
Finally, acting as a "post synthesiser", the metaphor appears even at the end of the instruction for the topic and concludes that concept, after which a new concept is immediately introduced.

2. 1. 2 c Metaphors and learning

As a cognitive aid
Metaphorical language and imagery, constitute a major cognitive aid and a means by which new thoughts can begin. According to the tensional or interactive theory of metaphor of Max Black (1962 & 1977), the formulation of a new way to express a concept consists of "seeing it as" something else, and selecting words accordingly. These in turn can persuade learners that this way of talking is valuable, and provoke an exploration of implications. If many implications are discussed in detail, learners arrive at either a metaphor or a model of the concept they were talking. The more successful these are, the more likely it is that they will be considered. Thus, metaphors are born as people struggle to understand and wonder "What can I say to make sense of this?". They tease the mind into action, exploring the possibilities in the juxtaposition which has been made. They grip the imagination, leading the mind or in some cases misleading it.
According to Grosslight et al. (1991), metaphorical language is a part of the constructivistic approach to knowledge which receives much more attention

in many fields of enquiry. Can the stimulation effect of metaphors, which has been so important in the creation of knowledge, be put to good effect in the re-creation of knowledge by individual learners? As mentioned in the Bullock Report (1975) knowledge is not something which can just be handed over but learners have to rebuild it for themselves.

As a cognitive conflict

The "anomaly" and "surprise" aspect of metaphors are of importance in the learning process. Both are possible ways of producing a cognitive conflict. Further on, Driver and Erickson (1983), Berlyne (1966), Festinger (1962) claim that cognitive conflict possesses significant value as part of conceptual change.

2. 1. 2 d Psychological processes in the comprehension of metaphor

Metaphors include "both motivational and cognitive aspects. One motivational issue concerns the reasons for the creation of metaphorical expressions. The general assumption is that metaphors fulfil the necessary communication function of conveying continuous experiential information, using a discrete symbol system. The three hypotheses pertain to the way in which metaphors fulfil this general function.
One hypothesis is that a metaphor provides a compact way of representing the subset of cognitive and perceptual features which are salient to it. A metaphor allows large "chunks" of information to be converted or transferred from the vehicle (familiar knowledge) to the topic (unfamiliar knowledge). The second is the "inexpressibility" hypothesis, which states that a metaphor enables us to talk about experiences which can not be literally described. The third is the hypothesis that, perhaps through imagery, metaphor provides a vivid and therefore memorable and emotion-arousing representation of perceived experience. These functions obviously imply cognitive processes, but they are intended to explain what motivates the use of metaphors in communication" (Ortony 1979, p. 151-152).
Basically the comprehension of a metaphor is a cognitive problem which entails the concepts of similarity, relation and integration, as well as the idea of novelty.

All psychological studies of metaphor involve "mediational approaches", in the sense that they are concerned with processes which mediate between the similarity, rational and integrative reactions involved in the comprehension of metaphors.

In the book "Metaphor and Thought" (Ortony 1979), contemporary cognitive psychologists (Anderson 1980, Stepich and Newby 1988) "interpreted such processes primarily in terms of structural and functional features of long-term or semantic memory". They also claim that "metaphor is a problem of meaning, which is based on long-term memory information associated with the terms of the metaphor.
Comprehension accordingly involves the retrieval of such information from long-term memory. The nature and organisational structure of the information is crucial to the analysis of metaphor, because that structure will determine what attributes of the topic (unknown or unfamiliar knowledge) and vehicle (known or familiar knowledge) will be likely to enter into, or mediate, the metaphorical relationship, given that there is access to those attributes by appropriate retrieval cues... But comprehension also involves "episodic memory", a term introduced by Tulving (1972) to refer to memories of specific, dated events, such as a particular list of words that one is required to memorise in a laboratory experiment... The metaphorical expression and the situation provide the retrieval context which guides the "search" through long-term memory. Since the linguistic aspects of the retrieval context are episodic events which fade rapidly, their influence will depend on their memorability, which in turn depends on such long-term memory characteristics as their concreteness or meaningfulness" (Ortony 1979, p.p. 154-155).

Research findings (Langer 1942 & 1948, Arnheim 1963) claim that the origin of metaphorical thinking is based not on the language but on the nature of perception itself, in "abstractive seeing". There is a relationship between metaphor of perception and imagery. Imagery is somehow involved in the comprehension and recall of some metaphors because of the fact that metaphors are originally chosen for their relative concreteness while imagery deals with information concerning concrete objects and events.

According to the "conceptual peg" hypothesis: Concrete nouns and pictures are effective pegs for storage and retrieval of associated knowledge (Paivio 1963, Pavio and Yarmey 1966, Ortony 1979). Metaphors facilitate a better conceptualisation because they provide the most memorable ways of learning and so they are the most efficient and effective tools. They are also epistemologically necessary in that they seem to provide a basic way of passing from familiar and well-known knowledge to the unfamiliar and unknown (Petrie 1979, p.p. 460-461).

In views of the nature of metaphor, two features are of particular interest and their implications on teaching & learning:

1) The same metaphor can be comparative from the teacher's viewpoint and interactive from the student's viewpoint. This possibility provides an understanding of how student's conceptual representations can be rationally changed.

2) Metaphors do not seem to be formal linguistic entities, as mentioned above. They can be used to create an "anomaly" or a "surprise" for students and can provide a new perspective on the situation.

The ways in which metaphors work on teaching & learning are presented below.

"First, an anomaly is created for the student, often through the fact that metaphor treated as a straightforward assertion would have to be false and teachers at least try not to utter falsehoods. The metaphors provide the one leg of a triangularisation by suggesting a way of looking at new, unknown material as if it were old, known material.

In addition to the new view, opportunity to be active with the new material is critical. Often this activity may be in the form of thought experiment only, but the activity, the acquisition of non-linguistic similarity relationships, is essential in providing the other leg for triangulating on the material to be learned. Corrections of initial triangulation and iterations of the whole process provide a mechanism whereby eventually the students' cognitive understanding of the material to be learned and his/her manner of acting on the material is significantly different from where the student begun and sufficiently like the triangulation enshrined in the disciplinary, collective understanding of material, to justify the teachers' claim the student have learned something radically new.

The metaphor has been considered as successful, not when we can say what it means, but when the triangulation allows the student to make judgements similar to those of experts in similar specific cases. Thus understanding the process involved in construing metaphor is what makes intelligible the ability to learn something new while admitting we must always start with what and how we already know" (Ortony 1979, p. 461).

Thus, according to Ortony (1979), the use of metaphors in teaching & learning consists of three phases:

1) Create a cognitive anomaly for the learner;

2) Offer opportunity for the learner to actively discuss or otherwise become active with the new ideas;

3) Provide corrective feedback to get the learner to understand the relationships between the known and unknown knowledge domains.

2. 1. 2 e Educational use of metaphors

2. 1. 2 e1) Tools of communication

In his research on the role of a metaphor as a tool which enables students to overcome active memory limitations, Ortony (1979, p. 475) discussed three different theses to explain how metaphor acts as a facilitator of learning:

1) "The "compactness thesis" in which it is asserted that metaphors work by transferring chunks of experience from well-known to less-well-known domains;

2) The "vividness thesis" which maintains that metaphors permit and impress more memorable learning due to the greater imagery or concreteness or vividness of the "full-blooded experience" conjured up by the well-known or familiar knowledge;

3) The "inexpressibility thesis" in which it is noted that certain aspects of natural experience are never encoded in language and that metaphors carry with them the extra meaning never encoded in language".

In the last two theses, metaphors serve as a tool for cognitive economy by facilitating the transference of information in large chunks.

An example from the instructional software can help to convey the importance of the teacher's understanding for choosing metaphors which are efficient communication tools.

Consider the well-known example of the snapping marbles for students to learn about electric current. This is a very common and familiar game for them. The software is trying to convey their feelings and experience from the relevant game to electric current. It is assumed that the context of the statements and the whole situation can guide learners to the intended interpretation of the statements in an efficient manner.

Additionally, the use of the metaphor is likely to cause learners to make inferences beyond those statements which can be literally expressed, and hence some of the effectiveness of the metaphor would be lost if the software or the teacher simply listed the important features of current or just gave a description of the current flow (see Ortony 1979, p. 477).

Finally, if a teacher carefully takes into account what students actually have to learn about a topic and what domains of knowledge students possess which can be used to reason analogically, then communication will be efficient and the students' learning will be supported both through the mnemonic power of metaphors and through engagement in the analytical thought processes involved in metaphorical thinking.

2. 1. 2 e2) Tools of thought

Regarding metaphors as a tool of communication, attention is needed to focus on their use for the exchange of information between the students and the teacher/researcher, when this exchange is caused by the software. Thus, metaphors are concerned with the discovery of inter-relationships between the two domains (familiar/known and unfamiliar/unknown) and an exploration of the extent to which they can be related.

For example, the metaphor of the "snapping marbles" for the electric current flow, as an energy transference between the electrons in a conductor's wire, is based on similarities in structure and function which are easily identified between domains of knowledge about marbles and electrons. Consequently, the recognition and explicit formulation of both similarities and differences latent in a metaphor follows.

Additionally, the effectiveness of images in overcoming active-memory limitations reinforces students' learning in the unknown domain.

According to Ortony (1979) metaphor can be used as a metacognitive tool to produce a cognitive anomaly and to provide the potential for resolving the anomaly by using the domains expressed in the metaphor and their relationships. Sometimes considerable surprise may be experienced as the implications of the metaphor are understood and conceptual change may occur.

According to Brown and Clement (1989) there are some assumptions inherent in such use of metaphors, for example:

1) Students have little knowledge of the unknown knowledge domain and would welcome a comparison to the known one;

2) They understood the metaphor;

3) They accept the metaphor as being sound because they recognise the aptness of the metaphor and the authority of the software;

4) They are helped to find the correct correspondences between the elements of the known and unknown domains;

5) They are motivated to attend to comparisons between the two domains;

6) A metaphor can be considered to be a "conceptual growth" because of students' improved understanding of the unknown domain.

As Brown and Clement (1989, p. 239) claim "we are attempting to build on students' conceptions in order to change their conceptions". The purpose of using metaphors is to engage students in a process of analogical reasoning and discussion among them so that students finally change rather than add to their existing knowledge [conceptual exchange (Hewson 1981) or accommodation (Posner et al. 1982)].

2. 1. 2 f Misconceptions and metaphors : Explanatory models help learning

When students have a "deep-seated" misconception it is important that a metaphor should not only be intelligible - which assists them to make correct correspondences - but should also provide them with a plausible explanation for the analogous phenomenon. Thus, the analogical relationship helps them to construct the new "explanatory model". According to Brown and Clement (1989) this kind of model is more plausible to them than an expedient metaphor because they discover that the key elements of such a model operate within unfamiliar knowledge. Under these circumstances these models combine the concreteness of the analogous phenomenon and the abstractness of the same phenomenon. In this process, it is worthwhile to mention that metaphors need to be used not only as a starting point in helping them to construct their new explanatory model but also as a pathway in engaging them to enrich new and unfamiliar knowledge.

2. 1. 2 g Interactive teaching & learning environment

The modelling framework of the software design was to stimulate concrete, causal explanations of abstract science concepts by making analogical comparisons. Activities and discussion highlighted specific analogical relationships between marbles and free electrons in metallic wires. This fostered the use of "moving crowd" experiences to construct a metaphor for understanding energy transference through wires. This instruction encouraged students to associate familiar imagery about electric current with the unobservable events such as transference of energy using the free electrons within wires in a circuit, thus anchoring new and unfamiliar concepts using meaningful language. It can be considered as motivational for students' reasoning at the microscopic level.
This idea is in agreement with Brown and Clement's (1989, p. 246 and 256) research findings. These researchers also found that in some cases it is more accurate to call it a microscopic model rather than a simple analogy.

Additionally, in recent research concerning mental models and modelling (Bliss et al. 1992, Bliss 1994 and Wild 1996) it was suggested that the process of

Abstract transfer	Explanatory model construction
Goal-conceptual growth	Goal-conceptual change
Student has little or no understanding of the target situation	Student understands the target situation, but understanding is non-normative
Student understands the base situation	Base situation (called an anchor) draws out a valid physical intuition
Student accepts that the analogy relation is sound (often simply accepting the authority of the teacher)	Student initially has difficulty accepting that the analogy relation is sound
Analogy helps provide abstract structure to the target situation by relating it to an already understood situation	Target already structured in students' mind, but this structure needs to be changed. Analogy helps student restructure by helping student construct a new explanatory model which enriches the target situation
Analogy is presented	Student is engaged in a process of analogical reasoning to evaluate and occasionally generate the analogies

Table 2-3

Comparison between two approaches of using metaphors/analogies: abstract transfer and explanatory model construction (from Brown and Clement 1989, p. 256) building models on a computer provides direct support for constructing strong and accurate models, which are central to the process of acquiring knowledge.

2. 1. 2 h Use of metaphors in Science Education

According to Flick (1991), science education can benefit from a better understanding of how personal experience can be applied to teaching. Recently many researchers (Treagust et al. 1996, Ogborn and Martins 1996, Ritchie 1994 and Brown 1994) pointed out that using a specific metaphor is a common instructional tool. However, teachers also need to be sensitive to the spontaneous or intuitive metaphors created by students, as Flick (1991) and Kaufman et al. (1996) claimed. People are not very good at explaining their own mental models of how the world works, thus knowledge bound up in personal conceptions is not readily accessible without explicit effort (Norman 1983). Teachers can help students explicitly study and examine ideas which may become intuitive bridges for understanding new concepts.

The role of metaphors in science teaching is mainly discussed from the viewpoint of their significance in the learning process. These serve significant explanatory and heuristic functions in the development of science (Hesse 1966, Leatherdale 1974). Thus, the role of metaphors in science must be considered to be an essential aspect of science teaching because this should enable learners to obtain both scientific knowledge and metaknowledge.

In their research findings, Grosslight, Unger, Jay and Smith (1991, p. 820) claimed that "it is important to provide students with experiences using models to solve intellectual problems. In this way, students would have the opportunity to learn that a model can be used as a tool of inquiry and that it is not simply a package of facts about the world that needs to be memorised".

2. 1. 3 DESIGN PRINCIPLES OF INSTRUCTIONAL LEARNING SOFTWARE

Over the last twenty years of research, development and production of instructional software, researchers have formulated principles for the following aspects of instructional software design:

a) Learner/computer interaction
b) Learner control

c) Sequencing of instructional events

d) Graphic screen design

These principles can be used by programmers and designers in the education and training setting during instructional software development phases when they design software for different purposes (demonstration, supplemental laboratory, or complete course modules). These principles are applicable not only to tutorials, but also to other types of instructional software (drill, exercise, tutorial, simulation, or problem-solving).

Many tenets of effective software design are derived from design principles inherent in the ideal instructional situation and ideal user interface:

* <u>From the ideal instructional situation</u>

1) one-on-one - instruction:

2) a patient instructor capable of providing endless practice with non-judgemental corrective feedback;

3) ideal educational material, e.g. a well written document such as an article or a book;

* <u>From the ideal user interface</u>

1) an easy to learn and understand computer/user interface;

2) a paradigm appropriate to the learning situation, e.g. a book, a computer model etc.

While the computer, as a two - way communication medium, is well suited not only for individualised instruction but also for group work learning (Johnson, D. and Johnson, R. 1986), it requires more skill to develop than any other medium. It is also an expensive medium. Ideally in the light of these facts, computers should be used when they can resolve an instructional problem (Leiblum 1982). Examples are:

* when they provide remedial or supplemental instruction, that is, when a computer acts as a tutor in a concept area which frequently presents learning difficulties;

* when a computer offers a capability (for example, simulation, animated pictures, calculation, graphics, automated performance record keeping or problem generation) that is likely to produce faster or improved learning;

* when a computer is used to aid drill, practice and problem-solving tasks which require frequent and large amount of corrective feedback to save on instructor time;

* when a computer is used to accomplish learning and instruction in remote areas where otherwise such an instruction is unlikely to be provided;

* when a computer can replace costly laboratory facilities.

In this study, the computer acts mainly as a tutor in the concept area of electricity, a concept area in which students have learning difficulties. It also offers the capability to produce improved learning, and to aid problem-solving tasks, which requires frequent and considerable amounts of corrective feedback.

2. 1. 3. a Learner/ Computer Interaction

Students can and have been asked to learn using a variety of media (film, audio tape, lecture, blackboard, overhead transparencies, books and computer). Only the computer and the one-to-one interaction with a tutor allow the learner to participate actively or interact with an instructional medium during the learning process. Consequently, this one feature - interaction- is at all times the most important feature of instructional computing software. Interaction within instructional software involves a cycle of presenting questions to the learner on the screen, accepting responses via keyboard or other input devices, having the programme evaluate the learner's responses and having the program provide appropriate feedback (Alessi and Trollip 1985, Bork 1985, Steinberg 1984). The way of presenting the questions, the frequency of the questions and the type of feedback have been the subject of research for many years.

2. 1. 3. a 1) Questions

Researchers claim that frequent questions allow learners to check their progress and focus on important points as well as motivating learners to progress further. Instructional software programmes benefit from attempts to maximise the number of appropriate, substantive, clearly-phrased and meaningful questions asked of the learner (Alessi and Trollip 1985, Steinberg 1984). It is best to avoid too many screens of text without any active participation on the part of the learner, in order to avoid the "electronic page turner" phenomenon and to avoid "verbatim" questions (questions that merely require the learner to copy text or image already on the screen and paste it on another screen).

2. 1. 3. a2) Responses

Questions require responses from the learner. The following points have been proved by researchers to be useful when designing questions in instructional software.

Firstly, prompts should be provided on when and where to respond, and as to what form the response should take (Alessi and Trollip 1985, Steinberg 1984, Merrill 1982).

Secondly, it is important to use an appropriate simple response format and use it consistently (Dumas 1988 and Rimar 1996).

Research has proved that, where it is useful to correct response, multiple choice (Joycey 1987, Fox 1983, Slade and Dewey 1983, Friel and Johnstone 1979) or true/false (Anderson 1983, Elton and Chelu 1977, Friel and Johnstone 1978) questions are best suited to instructional software.

2. 1. 3. a3) Evaluation and Feedback

Learner responses can usually be categorised into correct, "anticipated" incorrect and "unanticipated" incorrect responses. Each one of these three categories requires further consideration.

When evaluating correct responses, it is useful to remember the importance of evaluating responses as meaningfully as possible. Certain errors or variations in the format of the learner response may be allowed, depending on the actual topic.

When evaluating anticipated incorrect responses, it is useful to remember to provide a variety of feedback forms and types. According to Armstrong and Taylor (1971), Glaser and Lompster (1982), Hounsell et al. (1997) and Lennox (1998) appropriate feedback (relevant, instructional and kind) provides a learning opportunity.

<u>Informative feedback</u> for anticipated incorrect learner responses can eliminate misconceptions and improve learning (Hounsell et al. 1997, Lennox 1998).

<u>Confirmational feedback</u> tells learners whether their performance was correct or incorrect. It can be used immediately after a response as well as at the end of an instructional module. Such feedback has a positive effect on the beginner or inexperienced learner (Armstrong 1971, Merrill 1982).

<u>Motivational feedback</u> consists of comment to which a learner may react at an emotional level. Kind or positive feedback tends to keep a learner motivated, whereas insulting or degrading feedback quickly discourages a learner from continuing. Motivational feedback need not and should not be provided for every learner response. Many researchers, such as Hounsell 1997, Eckbled 1981, Armstrong 1971, propose non-threatening, warm, friendly, helpful, kind, positive and dignified feedback to be included, such as "Congratulations !!! Well done" as opposed to inane quips and patronising or degrading responses.

Instructional feedback is corrective or remedial, providing explanations, hints or cues towards a correct response. It does not only serve the purpose of telling the learner that his/her response is correct or incorrect, but also why it is correct or incorrect and how he/she can get to the appropriate response. Software authors should try to avoid screens where the feedback is irrelevant or provides confusing information. Instructional feedback can be used with most questions formats. Instructional feedback also helps learners by guiding them towards the correct answer and then reinforcing the correct answer via an explanation.

In this research, for incorrect responses a student can be given two or three opportunities to enter a correct answer and then be provided with the correct answer so that he/she can continue. Some researchers (Merrill 1982) claim that "Try again" loops can encourage the student who does not know the expected answer, to have another attempt, using the minimum and/or maximum help provided by the software, to proceed through the rest of the programme.

2. 1. 3. a4) Data

Once the learners' responses have been evaluated, they can either be stored for future use and reports' generation or they can be discarded. The computer is a marvellous tool for data collection, analysis and reports, so the opportunity to collect responses should not be overlooked (Alessi and Trollip 1985, Steinberg 1984).

The teacher/researcher can obtain the following from the computer:

* How each question was answered;
* How many questions were answered correctly or incorrectly;

but the computer cannot inform the teacher/researcher:

* Whether the learner actually tried to solve the problem or was merely guessing
* Whether the learner was actively engaged in the lesson.

The main purposes for collecting data are for improvement and for management.

For improvement purposes, an instructional programme ideally gives learners the opportunity to make comments at the moment something is puzzling them, but more often comments are collected at the end of a programme. It is possible, however, to collect every response a student has made in order to trace the path that the learner took. Collecting learners' responses allows the designer/teacher opportunities to revise and tailor the programme to the intended audience's needs, but the volume of data collected precludes using this strategy for students involving more than ten students, such as this research involving thirty first year University students. For management purposes, the number of questions answered correctly or incorrectly can be useful information for both learner and designer/teacher in order to guide further use of the programme. In the case that collected data is presented to the learner at the end of the programme, he/she often sees the need to direct his/her efforts to change his/her output.

2. 1. 3. a5) Ease of operation

A programme can be considered easy to operate when it facilitates learning of the content without any wasted effort spent on learning the operation of the programme.

According to Alessi and Trollip (1985), the programme should provide instructions as to how to operate it. In many cases, the screens themselves can communicate basic operating instructions. The summary screen for an introductory operating section can become the help screen to be accessed from any portion of the programme via a special keyword (button), such as the "Map" button. This can remind the learner that the help screen is available. Easy to operate lessons do not include instructions as part of a linear sequence with which the programme always begins. The learner should be able to get to instructions whenever necessary via a menu which facilitates the ease of the programme operation (Sommerville 1982).

2. 1. 3. b Learner control

According to Steinberg (1984) and Alessi and Trollip (1985) learner control over the sequencing and pacing of a lesson can be a motivating factor and it can continue to make a computer based learning event interesting and challenging rather than frustrating.

The degree of learner control is determined by learner features, the nature of the content and by the complexity of the learning task. Some content areas have a great need for sequencing while others may not. For less able or experienced learners and for low-cognitive tasks like memorisation, direction may be required from the instructional software. The degree of learner control for different learners, content areas and tasks has recently become an active topic of research.

According to Merrill (1982) learner control of display time is more desirable than computer control of display time. One way to allow pacing is to use a button to cue the learner to proceed. Timed responses can lead to frustration if an inadvertent interruption occurs, such as the learner dropping a pencil or a friend stopping to ask a question.

Learners usually need to page both forward and backward through the text or a lesson material within a menu. According to Merrill (1982) it is best to avoid forcing learners through a lesson in one direction only. It is also preferable for learners to be able to exit via a graceful exit -a command and/or a button- as opposed to turning off the machine. It is necessary both to allow the learner to exit at any point and to provide information on how to exit. Ideally learners should be allowed to re-enter where they left off. Software which cannot be exited and re-entered can be frustrating.

2. 1. 3. c Sequencing of instructional events

Instruction is an act of communication and therefore one must decide what is to be communicated, to whom (audience features) and how the content is to be communicated, that is, in what sequence the ideas are to occur (Peters and Johnson 1978, Steinberg 1984). Some points to be kept in mind for the design of instructional software are mentioned below:
Firstly, designers/teachers need to specify the purpose or the goals for the software. A programme beginning without an introduction does not give learners the opportunity to understand clearly what is to be covered in it (Alessi and Trollip 1985).
Secondly, programmes can present a general structure or give an overview of the total programme and paths through it to orientate the learner (Merrill 1982), for example, by providing the "Map" screen, i.e. a flow diagram for paths through the programme. Organisation and sequencing need to be well developed and they need to be communicated to the learner in the form of advance organisers or overviews linking one section to previously learned or existing concepts (Ausubel 1960, 1963 and 1978, Ausubel, Novak and Hanessian 1978, Jonassen 1982). If a programme is complex, it needs to provide recommendations on how to proceed through it most effectively. A programme without information on organisation or paths, even when it begins, can be confusing.
Thirdly, learning objectives for each component of a programme are desirable (Dick and Carrey 1978, Gagne and Briggs 1979). Some examples of objectives include: enhancing a skill, expanding knowledge or changes in the knowledge of the subject matter; increasing interest and physical and mental abilities. It is also helpful to specify, if possible, the degree to which these objectives are to be obtained in a testing situation. It is best to avoid ill-

defined, overly broad objectives, i.e. this programme helps you to understand physics or electricity.

Fourthly, when sequencing through the instructional software, it is useful to elaborate from simple concepts to more detailed ones (Merrill 1977, Reigeluth, Merrill, Wilson and Spiller 1980, Reigeluth and Rogers 1980). For instance, a programme can begin by focusing on the most important concept to be taught and elaborate upon it in stages of increasing details and complexity. As concepts are added, it is often helpful to return to an overview so as to tie all the concepts into an overall structure.

Finally, providing different opportunities for the fast or experienced learner versus the low or inexperienced learner increases the opportunity to individualise learning (Jonassen 1985). Some ways to accomplish this would be to allow learners:

* the option of taking a test before beginning a lesson, which would determine suggested paths;
* a number of variable examples based on their ability or experience;
* switching between different presentation levels;
* skipping over material because of their previous performance;

It is best to avoid forcing a linear path from the beginning to end. Fast tracks and slow tracks allow for a more individualised learning environment.

2. 1. 3. d Graphic screen design

Interactive graphing, windowing and animation differentiate the computer from most other media; but one must be careful to make use of screen formatting and graphics for readability and instructional purposes and not just for decorative or cute effects. Well designed screens can be a motivating factor. Some suggestions (See Alexandrini 1984, Alessi and Trollip 1985, Flemming and Levie 1978, Heines 1984, Larson 1984, Merrill 1982, Spannaus and Parisaeu 1985, Sweeters 1985) include, firstly preparing the layout so that it is pleasing and easy to read with no annoying features. Easy to read screens generally consist of text which:

* is well phrased;
* is legible;
* is indented and formatted, centred or left justified, but always in a consistent pattern;
* is structured in "natural eye movement sequences", such as from top to bottom and left to right;
* has consistently positioned functional screen areas;
* makes use of message design principles such as message clarity.

Readability is also improved by using different effects, such as highlighting with simple words (buttons), flashing pages, and/or using windows for emphasis and to communicate organisation. It is more effective to avoid crowding as much text as possible on the screen. This may be economical for a printed page, but crowding hinders the comprehension of text on a computer display unit according to Sweeters (1985) and Rimar (1996).

Secondly, the instructions have to be separated from the main text area so that the learner can look at the same portion of the screen for each types of information (Heines 1984, Larson 1984, Spanneous and Pariseau 1985). The answers area is usually placed below questions. The top line of the screen is best reserved for orientating information, such as the name of the section currently used. The bottom line of the screen is best reserved for options available via special keys, such as function keys, and any instructions on how to proceed.

Thirdly, graphics have to be used appropriately and for a specific instructional purpose, to convey a message or a concept, or to focus attention. Slow graphics or repeated decorative graphics can become tiresome and interrupt the flow of the lesson (i.e. the word "hello" 'walking slowly' across the screen).

Further details are presented in the next section.

2. 1. 3. e Design principles from the viewpoint of learning

As mentioned in section 2. 1 of this chapter, learning is a constructivistic process where the student plays a central role. This process can be greatly enhanced by a proper open environment, which provides tools to make students aware of their own thinking (Burton 1988). Thus, reflective learning and the development of metacognitive skills are promoted. As a consequence, designers/teachers have to design learning environments to diagnose students' models and to make students aware of them.

Given that students' models are generally different from these of scientists, the programme must also be able to promote conceptual change by strategies, such as:

* Making students aware of their own models;
* Explaining to the students the differences mentioned above;

On the other hand, the students' exposure to the consequences of the use of their models conflicting with the results of the application of the scientists' models, seems a suitable strategy to promote cognitive conflict and consequently help the students' conceptual change.

One of the origins of students' ideas are their daily life experiences. Therefore computer environments should also provide tools with which the students could simulate those experiences. This will also make it easier for the student to understand the relations between daily life experiences and physical interpretations of the phenomena; this increases learning integration.

Students explain physical phenomena using qualitative reasoning; thus, the explanation delivered to the students by the programme should also be based on qualitative models.
The design of educational software must be based on carefully designed teaching sequences. These teaching sequences must take into account, among other things, the students' models and their progression (Loureiro 1992), as well as their psychological profile.

The success of learning sessions is dependent on the nature of the information gleaned by the students (what information and when). If training consists of problem-solving with the opportunity of feedback, a student who rarely asks for feedback or is inattentive to feedback is not likely to benefit.

The programme developed for this research attempts to diagnose the conceptual models that students use when solving scientific problems. It focuses on a conflict-based approach to using exploratory environments which encourage students to note discrepancies between their expectations of a circuit behaviour and their beliefs. The whole activity is intended to promote self diagnosis by the student.
For example, the student is to be encouraged to find a diagnosis which accounts for any discrepancy that she/he has detected. If the student can see some discrepancy between her/his beliefs and their consequences then the possibility exists that teachers/designers may be able to offer some further support as the student seeks to debug his/her own conception of the physical world. From source books it is evident that different strategies have been proposed to handle different kinds of misconceptions, such as approaches based on misconceptions about causal relationships (Stevens and Collins 1977), object-related misconceptions (McCoy 1988) and plan-based misconceptions (Quilici 1988). Many approaches require the use of dialogue

either to generate a diagnostic probe or to remediate a misconception. Thus, the main tools are the construction of tasks to promote an increased chance of generating a conflict and the use of diagnostic probes.

2. 1. 3. e1) Cognitive conflict and learning

The idea of using cognitive conflict in teaching & learning is not actually a new one. The design of the software is based on a particular way of using questions to teach a "system view" of the electric circuit. To use cognitive conflict is to put the student in such a situation that his/her own ideas are inconsistent with logic or experimentation. The first requirement for using cognitive conflict is the knowledge of students' ideas. In this respect, electricity is a good field. Sequential reasoning without conservation of current is another very frequent reasoning students use (Shipstone 1984, Closset 1983). So, as mentioned in the previous section, they answered questions incorrectly because of this reasoning. Their first reaction was to refute the results. Then they started to modify their reasoning just enough to make it consistent with the experience that they were assimilating. It seems that the only way for a student to accept the correct answer to the question is to change his/her sequential reasoning.

2. 1. 3. e2) The use of models as an aid for the organisation of concepts into a hierarchical cognitive structure

Students often learn physics completely or partially by rote. The traditional organisation of physics texts is logical and follows the historical development of the discipline, but it does not "work" psychologically. Cognitive scientists have investigated how information is organised and processed. Concepts are organised, in our memories, into a hierarchical cognitive structure.

New concepts are most efficiently learned and retained when they are linked to existing general concepts already present in the cognitive structure of the learner. Not only should a re-organisation of the subject domain where the concerns will be adequately addressed be done but also the atmosphere of the classroom must change. Students must grapple with the new concepts through discussion and application, such as problem solving. Students were encouraged to focus attention on the structure of the knowledge they were learning. The heuristic aid, which is used for explicitly bringing out this structure, is the use of models and analogies. Models were recommended for organising the subject domain. They visually illustrate how new concepts relate to those which have already been learned, and the knowledge tree shows the process of studying an event in terms of concepts and principles needed for its analysis.

Recent research has led to the identification of specific difficulties students have when studying electric circuits. This detailed knowledge makes possible the design of instructional material to meet students' needs.

Firstly, the research has found that some students fail to correctly solve dc-circuit problems mainly because of sequential reasoning (Shipstone 1984, Gott 1985, Picciarelli, di Gennaro, Stella, and Conte 1991). Thus, one of the targets of the design of the software was how firstly to diagnose students' sequential reasoning and secondly to treat this kind of reasoning.

Secondly, in students' minds, a specific concept, i.e. connection in series, becomes so closely associated with an image (aligned resistors) so that no difference is left between the concept and its pictorial representation. According to Caillot (1985) students' mental representations of dc-circuit problems come from surface features which are of a pictorial nature. They probably store concepts in their memory, such as resistors in series or in parallel under a prototypical image, instead of a list of their attributes based on physics principles underlying the properties of these circuits.

2. 1. 3. e3) Interface

The interface is critical to the success of software, and must be considered in the design phase of the software. The interface should be easy to use, although there are no well understood methods for creating such interfaces.

(I) Human-computer interaction

Semantic and syntactic models of user interaction and interface design exist. Since semantic knowledge about computer concepts has a logical structure, this knowledge is expected to be relatively stable in memory. When using a computer system, users must maintain a profusion of syntactic knowledge.

There are four popular interaction styles :

1) <u>Command language</u> which is flexible but requires substantial training.

2) <u>Menu selection</u> which shortens learning and structures decision-making but may slow down frequent users.

3) <u>Natural language</u> which relieves the burden of learning syntax but requires clarification dialogue.

4) <u>Direct manipulation</u> which visually represents task concepts and may be easy to learn.

While menu selection is attractive because it can eliminate training and memorisation of complex command sequences, direct manipulation seems to be the best alternative for a wide variety of users (Scheiderman 1986). By the use of direct manipulation rather than command language even a novice can begin using a computer system immediately. Direct manipulation eliminates the possibility of errors from incorrectly typed commands.

Designers should recognise the diversity of interaction styles. Novice users have no syntactic knowledge of computer issues. For them the computer system should have few options. Expert users demand rapid response and great flexibility.

Research on information display design (Jenkin 1982, Burkhardt, Fraser and Wells 1982) has repeatedly shown the need to model dynamically the human cognitive processes which occur when the information is being displayed. Factors positively affecting acceptance at one point in the interaction may have negative effects at other points (Normore 1984). In a dynamic system, the information available to the user at any time preserves the context of interest to the user, in contrast with a static display (Mitcell and Miller 1986).

(II) Browser interface

Browsers may not have any clear indication of the type of information that they want. Browsing is defined as "the art of not knowing what you want and finding it" (Cove and Walsh 1988). There are different types of browsing, depending on whether the user has many unrestricted options or not. Links always take the user somewhere else, but do so for various reasons. Each link type should have distinct and standard types. For instance, a button, which takes the user to the beginning of the document (the map), is consistently represented with a certain picture. A button, which takes the user to the next page, is represented with an arrow pointing to the right.

2. 1. 3. e4) Motivation in human-computer interaction

According to Rivlin, Lewis and Cooper (1990) the most significant factor in designing instructional software was the motivation of the user. Thus, users that were highly motivated to perform a certain task interacted much more with the computer system than those whose motivation was lower. Human-computer interaction is mainly dependant on user's characteristics -which are age and motivation. Jenkin (1982) mentioned that "the program in action brings in the whole range of variables related to teaching". Among these

variables he gave emphasis on "what motivation the program offers", as one of the important factors in promoting an effective software design.
Based on cognitive theories of motivation, Lens (1994) argues that computer assisted learning can enhance several types of intrinsic motivation because it allows for highly individualised learning. Educational psychologists (Salomon 1983, 1985, Lepper 1985, Lens 1987, 1994) have evaluated the motivational effects of instructional designs, such as CAL, on the learning process itself and the variables or processes via which these motivational effects work (e.g. direction and range of attention, degree of involvement and/or mental effort, mindfulness, types of presentations). Additionally, other researchers (Nygard 1977, Rand 1987, Atkinson 1978, Parker and Lepper 1992) propose that making learning more fun and more attractive not only has additional positive effects on the learning process but also increase the time learners spent doing it.
Finally, CAL can stimulate the intrinsic motivation to learn because it allows for highly individualised learning tasks. However, according to Lepper et al. (1993) effective CAL requires not only good software but most of all teachers who introduce computers to their students as a learning & teaching tool.

2. 1. 3. e5) Imagery - Roles of images in the computer systems

It is common sense that much of the attractiveness of computer systems is based on their visual appeal. As previously mentioned in section 2. 1, icons are visual symbols for entities or actions. Icons are powerful tools for representing information. The opportunity to link part of an image to an elaboration of that part is attractive. According to neuroanatomy, this feature may allow the user to navigate through the different levels of the brain.

The role of imagery in a computer environment is major but not as clear. A consistent role for images in human communication is sometimes difficult to determine. When asked to place instructions on paper for someone crossing a town from one place to another, most people write text and do not use diagrams. When asked whether they would include a diagram if giving such information, most say yes. Further more, when asked how they would like to be given such an information, people say they would like a diagram (Wright and Lickorish 1989).

As mentioned above, human memory can be viewed as consisting of three types: long-term memory, short-term memory and external memory (Simon and Newell 1972). The external memory may come in the form of a computer graphics screen. Psychological research suggests that individual differences in cognitive style significantly affect the way in which a graphics screen can help a problem-solver. People who score high on certain psychological tests are called analytics and are good at imposing structure on a problem. Those who get a low score on this test tend to rely on intuition. In certain experiments, short-term memory limitations prevented analytics from solving a problem that non-analytics could solve. With a graphics screen to augment their short-term memory capacities, the analytics solve the problem more quickly than non-analytics (Pracht 1986).

(I) Images

Throughout history, images have been used to express knowledge. Research on pictures which accompany text is extensive. Thus, it has been argued that pictures enhance memory (Reid et al. 1983, Nelson et al. 1984, Pesdek and Stevens 1984). In relation to computer graphics it has also been argued that they enhance learning (Hammond 1971) and knowledge acquisition (Baltz 1977, Reif 1986) because they contribute to the process of imagining topics which are otherwise difficult to grasp. Similarly, as per the above mentioned researchers, Nielsen (1990) emphasised on the role of visual dynamic graphics in the process of knowledge acquisition through the use of computers. In previous research, Nielsen (1987) claimed that it was the graphics and illustrations which fascinated and motivated fifteen year old pupils. He concluded that it was visual perception which ruled pupils' work and though they had a very clear perception of the relationship between text and graphics; dynamic graphics were decisive factors in their problem-solving.

(II) Imagery

According to Kosslyn (1983) and Nielsen (1990) imagery representation has a positive influence on cognition. Consequently, the use of pictures and icons is fruitful in learning processes. Nielsen (1990) claimed that the fifteen year old pupils actually "operationalize their visual perception by reading the dynamic graphics. The reading allows them to move from immediate perception to a preliminary understanding, as they acquire visual knowledge. In this process the dynamic graphics function as a mediator for the knowledge acquisition and the ability to read dynamic pictorial information provides a means for understanding, when working with image media".

According to Kosslyn (1983) the process underlying the ability "to operationalize the read information in the dynamic graphics" is visual operational thinking, which is a prerequisite required to link between concrete operational and formal operational thinking. Referring to graphics and the psychology of thinking Arnheim (1963) also proposed new ways of understanding the information embedded in graphics and painting in his book "Visual Thinking".

2. 1. 3. e6) A knowledge-based system : Design issues

(I) Objectives

A knowledge-based system focuses on the support of discovery learning, which is based on the creation of cognitive structures and cognitive manipulation. Consequently, the provision of appropriate representation related to an internal cognitive structure encourages the following three learning activities:

(II) Concept acquisition

In knowledge-based systems, concept acquisition is activated by a representation of a subject domain. This representation should contain "anchoring concepts", which can be related to newly-learned concepts by the user of these systems. According to Ausubel et al. (1978), concepts are "objects, events, situations or properties that possess common criterial attributes and are designated in any given culture by some accepted sign or symbol". Because discovery learning requires the availability of facilities for organisation, manipulation and extension of cognitive structures, these facilities are provided. Users of these systems can also discover existing inadequacies within the representation, and compensate for discrepancies by modifying their cognitive structures (Philips 1981).

In addition, the user is helped to express, organise, clarify knowledge already gained and create a new cognitive structure. The whole process can stimulate personal creativity, expressivity and increase various skills and abilities.

(III) Symbolic perception and processing skills

For a continuous development of symbolic perception and processing skills, within the age-range of interest, knowledge presentation in simple symbolic form is appropriate. Researchers, such as National Council of Educational Technology 1993, Salomon 1994, examine whether simple symbolic forms are still valid when computers are used to stimulate thought.

(IV) Skills

There is important evidence that I. T. skills enable the storage, retrieval and communication of information. Alvin Toffler's (1970) book "Future Shock" is considered excessive and over exerting. However, its author emphasises valid aspects of education in the future. Taking into account that facts are changed continuously and rapidly, the ways of teaching & learning that he recommends are based on the manipulation of knowledge rather than the knowledge itself.

In the School Curricula in England, Wales and Scotland, emphasis was given on the use of computers "across the curriculum" and the development of I. T. skills. These skills can also be enhanced by students manipulating a symbolic representation of knowledge that is more qualitative and less quantitative than that stored in a database system.

2. 1. 3. e7) Design criteria

In the design of the software, certain features are examined and taken into account. These are:

1) A flexible tool which enables students of various abilities to use it effectively;

2) An appropriate symbolic method of representation which can be used by students of various abilities;

3) A facility to highlight discrepancies or inadequacies in the cognitive structure;

4) A tool which enables students of various abilities to create, explore, manipulate, extend, amend and organise their knowledge structure and retrieve information from it.

With regard to a detailed design:

Architecture

As a knowledge-based system (Purchase and Robinson 1990), the architecture of the instructional software was based on the educational and psychological criteria of design as mentioned above and aims itself at students' enthusiasm to learn.

The software contains the following components:

Knowledge representation

Knowledge representation comprises the internal representation and the external graphical representation. Both can be browsed and manipulated. The latter is like a mirror of the former. As pictorial representation of knowledge was used, the picture had to be simple enough so that it was clearly perceived by the students. This representation should be both powerful and flexible enough to be appropriate for a variety of abstract concepts.

An adequate representation of concepts and the various relationships between them is required for the design of knowledge-based systems. According to Quillian (1985), Minsky (1985) and Purchase & Robinson (1990, p. 444), there is in progress "a semantic network knowledge representation

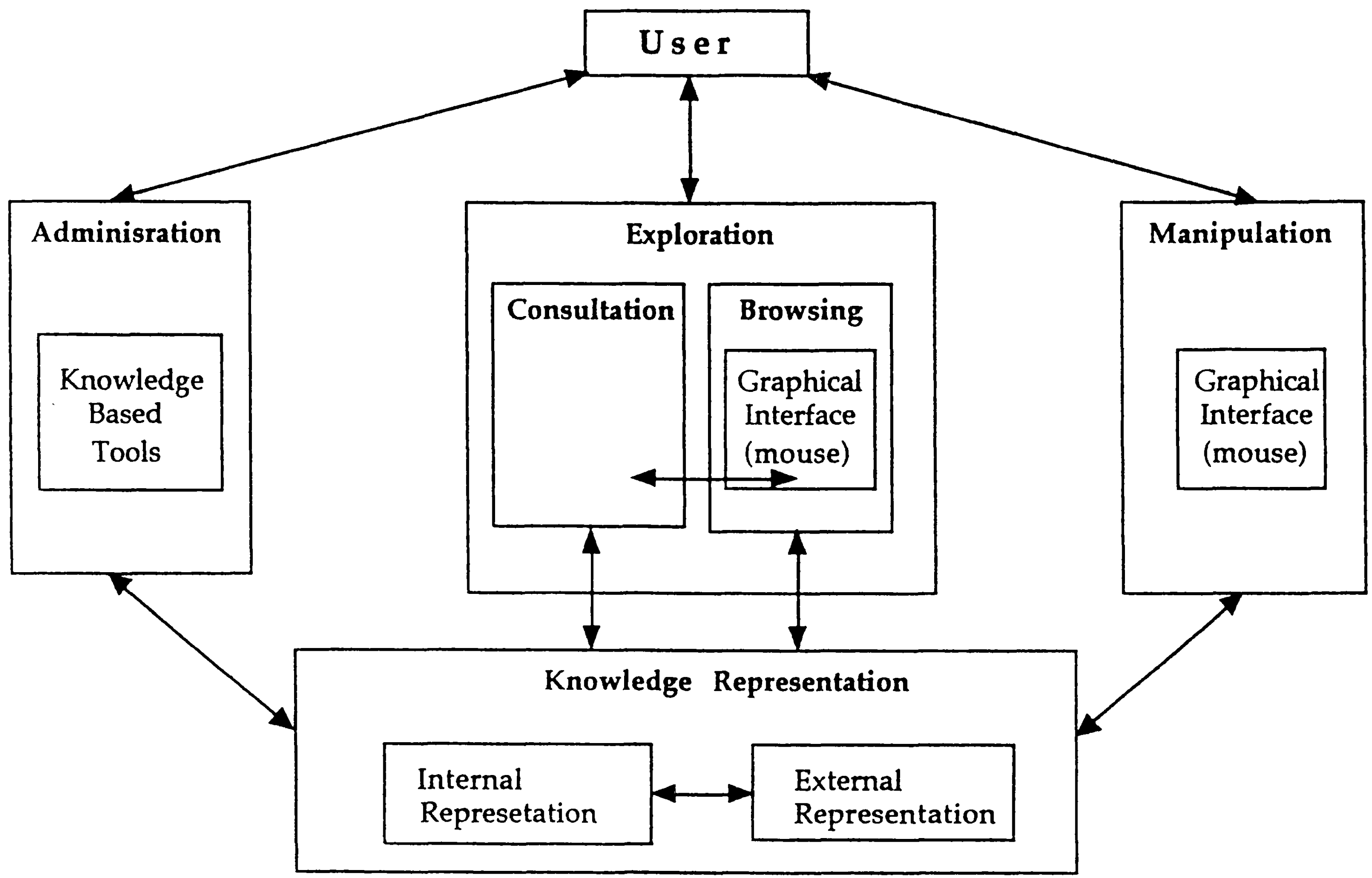


Figure 2-3
Architecture of knowledge based systems
[from Purchase, H. and Robinson, B. (1990) p. 444]

which combines ideas from an associative form of knowledge representation and a structural one". In such a network, not only are "important relationships between concepts to be made explicit" but also "less important ones could be embedded in frame structures so as not to make the network unnecessarily complex". The researchers support that this representation "is more appropriate for the modelling of cognitive structures than for production of rules or logical expressions and is therefore more likely to be understood by young children".

In addition to the above mentioned, it is also more likely to be understood by students of various physics background, as was the case for this research.

Exploration

The student can explore the subject domain in two ways:

a) Browsing

Browsing the graphical representation entails the direct manipulation of elements in the knowledge structure by using a mouse as the interface device.

b) Consultation

It is possible for students to understand the subject domain by accessing the theoretical feedback provided.

Manipulation

From the viewpoint of the presentation of knowledge, the software was suitable for flexible expressions of the subject domain of electricity and so it enabled the students to change their own knowledge structure to compensate for any discovered discrepancies or inadequacies. A mouse was the appropriate interface device for manipulation, not only for browsing but also for consultation.

Administration

The software was a tool similar to databases and spreadsheets. Although the students come from a different background knowledge in physics, it enabled them to use its theoretical feedback, as created by the researcher/their teacher. In addition, the software not only provided manipulation but also facilitated acquisition of the entire knowledge in the subject domain.

2. 1. 3. e8) Basic pedagogical orientation

The basic orientation of the actual research was to offer environments where students were engaged in an active learning process. We think that exploratory activities could help the students identify basic concepts in the area of electricity, so as to understand its general trends and, eventually, to feel the need for formalisation of their discoveries. After such a process, students would be able to undertake an initial formalisation and to be more receptive to a more complete presentation by the teacher. This presentation then appeared as a synthesis and clarification of a set of personal experiences.

The possibility of such open pedagogy being effective in the classroom is a sign of an important breakthrough. In the usual chalk-and-blackboard environment of the classroom, it is well known that open approaches give rise to very difficult implementation problems. How can a teacher really assist many students involved in an active exploratory process? At first, it was not clear whether computers would bring important changes to teaching methods in schools. Their use was limited to programming courses and computer-assisted teaching with tutorials. Tutorials guided the student through pre-determined paths which were far from compatible with an active learning process (Heinbenstreit 1986).

The construction of new knowledge requires a more open approach favouring multiple representation schemes. With generic software, such as text and image processors, spreadsheets or data-base managers, it is possible to build specialised software tools. Coupled with learning activities, these tools can help the acquisition of important knowledge and skills such as searching, structuring, representing and transforming information on a given subject. Furthermore students' activity in a such an environment may help them to develop higher cognitive capabilities, such as: discovery of general relations between attributes of objects,; hypotheses testing, modelling and explanation formulation (diSessa 1987, Collins and Brown 1988).

Multimedia systems, such as HyperCard, have been developed in the same direction and have been made available on microcomputers. These systems favour knowledge organisation and presentation in ways far closer to natural thought processes than traditional database systems. These new generic tools can help build learning environments in which students can experience a constructive exploration of a field of knowledge (Gaines 1987 and Farrow 1993).

2. 1. 3. e9) Pedagogical impact on learning

As mentioned previously, the aim of this research was to design and evaluate some essential concepts for studying Electricity within an exploratory learning environment. Other similar studies ought to be necessary to evaluate their impact on learning.

However, some general principles can be illustrated by the tests, observations, interviews and questionnaires that were gathered during classroom experiments. For example:

Working in this kind of environment the students should show a great deal of motivation. Examples of their motivation follow:

1) They were quite involved with modelling activities provided by the theoretical feedback of the software;

2) They were also excited both after answering the questions with the help of the tools provided and when the results of the evaluation of their work were shown on the screen by the software;

* Even students with a poor background knowledge of physics wanted to succeed in these activities and they tried hard, using assistance from the software-provided help, other students and researcher.

Most students should succeed in most of the tasks set by the designed software. The use of this environment contributed to interactive knowledge acquisition because:

1) Students not only manipulated but also visualised electrical concepts in different ways;

2) The precision and clarity of computerised textual, numerical and graphical representations supported students' concentration on the electrical concepts instead of computations and sketching precision;

3) The computer's fast processing facilitated the treatment of a larger quantity of knowledge in less time, therefore students' cognitive activity increased;

4) Using these software knowledge tools and exchanging their ideas with others, students were encouraged to detect their own errors and mistakes, and could also debug their own knowledge;

Finally, "this interactive knowledge acquisition should favour the integration of new knowledge into mental schemes and therefore increase the chances of long term retention" (Bordier, Paquette and Carrier 1990, p. 1059). Students felt satisfied using the software because they were active participants in the teaching & learning process.

2. 1. 3. e10) Domain-based learning environments

The aim of computer environments which include an extensive representation of a knowledge domain whether explicit and/or implicit, is to teach the user the subject matter. The method of communicating this knowledge is not through explicit instruction but via exploration, manipulation and action within the domain representation.

These environments can take on various forms. For instance :

a) "Microworlds" which allow the explicit manipulation of objects and variables according to various constraints and procedures whose interaction defines the domain, often by analogy (Papert 1980 and O'Shea et al. 1988).

b) Simulations which provide an explicit graphical representation of a process to be taught and by changing the values of variables and seeing their effect, the user can come to understand how the process works.

c) Animated pictures which give a sense of movement have a big impact on the user-learner.

All these forms are included in the area of Artificial Intelligence.

2. 1. 3. e11) What is Artificial Intelligence ?

Artificial Intelligence attempts to help students' understanding of their way of reasoning and to assist them in reasoning better. On the one hand, it endeavours to construct computer software and hardware which mimic or model human thinking and behaviour. On the other hand, it is focused on designing tools and techniques to help students harness their "mental powers" more effectively. These goals are sometimes intentionally or accidentally combined. In the area of Artificial Intelligence, research focuses on "mimicking the mind". As a result, researchers examine and study the human mind and the ways in which people solve problems. Therefore it is natural that this research becomes involved with education.

2. 1. 3. e12) Intelligent Tutoring Systems (I.T.S)

Much assurance comes from the Intelligent Tutoring Systems. These manage to automate both the knowledge and the experience provided by specialists in the subject domain and the guidance provided by experienced teachers. Therefore, I. T. S not only offer domain knowledge and pathways for knowledge acquisition through a programme of study, but also monitor students' progress appropriately. If fully realised, these systems enable learners to obtain tutoring which matches to their needs through a didactic teaching approach. In compulsory education the use of I. T. S and their impact on learning are still at the research stage. Nevertheless, they provide both students and teachers with an important insight into the many directions for educational software in the future, i.e. software with an interface engaging learners in an intelligent dialogue.

2. 1. 3. e13) "Microworlds"

"Microworlds" have been built for some systems, such as:

1) The LOGO (Papert 1981) is a product of A. I., which has already become widely used throughout the world, especially in primary education. LOGO was designed to provide learners with a computerised environment in which learning is a result of exploration. Instead of the didactic teaching approach adopted by most tutoring systems, learners are in charge whether they have the teacher's help and guidance, or not.
2) ARK - The "Alternative Reality Kit" (Xerox) is written in the A I computer language SMALLTALK and allows students to explore physics.
3) Stella (High Performance Systems) provides an environment for dynamic mathematical modelling, useful for economics, medicine and other subjects.

The systems mentioned above provide learners with a certain language which enables them to communicate with the computer. So:
1) LOGO provides certain commands from young learners' own vocabulary.
2) ARK and Stella provide a graphical language in which a model is constructed from representations of physical objects.

2. 1. 3. e14) Knowledge based tools for education
"Microworlds" can be described as a knowledge based software tool, but the range of such tools is much wider. They involve improving the tools which are available to the teacher and student to assist them in learning. They range from simplified programming languages up to expert system shells. These tools can play diverse roles within classroom interactions.

2. 1. 3. e15) Modelling knowledge tools
Modelling knowledge tools are used by teachers and students to enable them to "author" advanced level programmes which support their learning, as well as building and exploring models. A considerable amount of support and guidance are required by the teachers so that students are able to use these tools effectively. It is argued that they generate teacher - student discussions and debates. These created programmes are sometimes useful in their own right, but it is the process of creation which is being encouraged (Nichol, Briggs and Dean 1987). However, these are part of the process of learning a topic, and cause researchers' motivation for study as to whether students using these programmes improve the order and structure of knowledge which has already been gained using other approaches.

2. 1. 3. e16) HyperCard : Future direction
Educators should be more interested in Artificial Intelligence programming. Powerful knowledge based tools and object-orientated approaches are within reach of education. HyperCard is a tool which builds upon an object-oriented

paradigm. It has received considerable attention and interest from teachers in all stages of education, and also educational software designers, who have recognised that "HyperCard is a major breakthrough". It is also a tool with which professional looking and well-presented software can be designed quickly and easily, even by people with limited prior programming experience.

HyperCard's weaknesses lie in its programming language, HyperTalk. This "scripting" language, a nearly-plain-English one, enables the user to associate sections of a programme with fields, buttons and cards. HyperTalk has been designed as a compromise between a natural way of instructing computers and a full programming language. A look at the range of "stacks" currently available indicates that much processing of knowledge is available.

HyperCard's strengths lie in its ability for further separation of components within the programme. In addition to the knowledge and the "shell", the interface also becomes a discrete entity. This will allow considerable experimentation as to how the interface "looks and feels" without altering other modules.

The simplicity with which the interface can be created enables teachers and students to tailor the interface to their own preferences. According to Farrow (1993) and Cockerton & Shimell (1997), by using HyperCard learners can use software which involves them in actively manipulating the material that they are studying.

Buttons

Buttons were the main means by which users could control what stacks did for them. Generally, buttons are also used as a general purpose tool by HyperTalk scripters to provide functionality to stacks.

Two kinds of buttons were used:

a) Buttons for navigation;

b) Buttons for interaction.

First, the emphasis on button design in this package focused on making them obvious and clear -where buttons were and what they did. They were also distinguishable and users could get the required information simply by looking at the button. For example, clicking on the "Animate !" button allowed the user to see an analogy of the flow of current through a wire by animating the flow of water through a hosepipe.

Second, the buttons for navigation were put on every card in one certain place; they remained visible and accessible, regardless of what users did on the card; while the buttons for interaction changed from one card to another. For instance, if users produced pop-up-fields then these did not hide the navigation buttons. With this in mind, the background layer was best for navigation buttons, while the card layer was best for buttons which were card-specific or buttons for interaction. Arrow buttons were used for navigation. Using a book metaphor the arrows pointed sideways because that is how pages were turned. A right-pointing arrow appeared to move the users to the right and these were accompanied with a visual effect such as a scroll or wipe left. All this helped users to orientate themselves. At the same time, it was an easy way to reinforce students' navigation and to support the software's general metaphor, as well as matching the visual style of the screen. Although arrow buttons were a small visual part of most screens, they were of great importance for the users' navigation.

There were various kinds of buttons for interaction, mainly icon buttons, which had icons associated with the button itself and with its function. These buttons were used for purposes similar to the icon's message. Additionally, in some cases, dialogue boxes were used to provide another way to interact with users.

Fields

Text refer to the verbal information of the stacks. The stacks focused on what the text should say to the users and how it should work with graphics and sound as effective as possible. Thus, the text's content is a separate issue from its graphic appearance. The tone of the textual voice was as important as the tone of the visual design. In both textual and visual design humour was used carefully as it livened up the whole software in combination with visual and sounds effects.

The standard field had several options: transparent, scrolling, opaque and pop-up-fields.

A designer has several considerations when writing a text in a field for stacks: accuracy, clarity and conciseness; readability and flow; grammatical and usage correctness; and appearance on the screen. Words that are understandable on isolated cards and that flow well across a sequence of cards free the user-learner to focus on the message of the stacks. Correct grammar, punctuation and spelling give the user-learner confidence in the accuracy of the stacks.

Graphics

According to Horton (1990), pictures are used "to explain and describe; to express visual and spatial concepts; to help learners imagine complex processes; to highlight important points; to attract and focus attention; to show complex relationships (e.g. "graphical organisers" or "graphical browsers"); to motivate and attract users; not for decoration". The effects of pictures within computer based learning packages have not been empirically studied to a wide extent. Underwood (1994) summarises some of the findings from the effects of illustrations in paper based learning materials. Thus, it is claimed that pictures "can help learners understand what they read and also remember it... They should serve a distinct function in the learning material ... and may be a good way to develop mental models".

In this software, the graphics used are:
Representational : where objects are represented as they actually appear (to different extents of refinement and detail).
Analogical : where a concept is expressed via a representation that "does the same" or "works the same way" to enable the understanding of new information from existing knowledge.
Abstract : where the referent of the depicted object is a concept or idea which is conventionally associated with the picture/icon.

In the context of user interfaces Apple (1987) says that "where they are clear and consistent, graphics contribute greatly to ease of communication, learning and understanding".

HyperCard is a visual medium. Its graphic elements such as visual style, card layout, metaphors, illustrations, typography, visual effects and animation were an integrated part of every stack. They were an especially powerful communication tool.

Metaphors on both the technical and subject domains made the whole navigation and exploration in the subject area to be simple. A clean layout ensured that the users were able to focus on the content. An integrated visual style, in which illustrations, typography and animations conveyed a single message reinforced the purpose of the stacks.

The effective graphic design focused mainly on simplifying the card's grid, separating permanent buttons from card specific ones and moving related elements close to each other on the screen.

Visual design

As mentioned, it was of importance during the design phase of the software that the visual style of the stacks was consistent and suitable for the users, that understanding the subject matter was made easier due to the style of presentation and by employing metaphors, and that it was fun most of the time by using cartoons and a playful style.

Card layout

Cards in HyperCard essentially consist of two layers: the card layer which is transparent and the background layer

Common card elements were text, illustrations and other graphic elements. According to Horton (1990) consistent card layout gives the users a feeling of stability and lessens the teaching normally required. Those elements common to most or all cards best belong in the background. Specific card elements belong in the foreground or card layer. Users often focused on the card elements -which changed from one card to another and were shared by few cards- although the background elements gave the stacks their distinctive look, because they formed a context for the card elements.

Grids and labels

For most stacks , some kind of invisible grid layout was used. A grid layout was one in which certain areas of the screen have been blocked off for specific functions.

A few rules which were kept in mind during the design phase were:

a) To keep layout simple;

b) To use size to indicate priority : to make important things bigger;

c) To put permanent buttons along the card's edges;

d) To make permanent buttons small;

e) To separate permanent navigation buttons from the card-specific ones;

f) To put buttons which change part of the screen next to the thing that they affect.

Illustrations

As mentioned, HyperCard is a visual medium and so illustrations were a way of using HyperCard's power.

The illustrations were generally pictures which appeared in some stacks, whereas graphics or visual design referred to all visual elements. They were used because they could enrich the whole software design and illuminate points in the subject domain. The focus on using illustrations was to weave the text and illustrations together -each doing its own job- so that they formed an integrated unit. Thus, a full illustration with simple text often conveyed as much information as a long piece of text alone. Such an illustration presenting all the components in meticulous detail reduced the text required and elicited reasoning and problem solving skills (Lindsay 1988, Nielsen 1990).

While using illustrations, which seemed to pop up and covered part of the card, as with the "show card picture" command, care was taken not to hide essential buttons and text. Illustrations were chosen to match the software

graphic look. Cartoon imagery and photographic quality art were used, as appropriate to users, subject matter and the purpose of the stacks.
Scanners were used as the fastest and easiest way to produce high quality photographic, freehand and other types of illustrations for the stacks. Thus, a wider and freer variety of styles were given to the stacks, as according to Horton (1990).

Visual effects
The visual effects of HyperCard worked powerfully as they were chosen to be consistent for a certain action. Students mentioned that they associated the visual effects with the appropriate action. This fact is also in line with research findings (Ambron and Hooper 1988, Rada 1991). The chosen effects were crucial to the meaning or operation of the stacks as they gave emphasis to certain points in the subject domain.
<u>Dissolve</u>
Dissolve was one of the most frequently used effects, mainly because it conveys a purposeful slowing almost as if the transition itself were important or the two cards sufficiently different that the user needs time to adjust. For instance, in the stack "Software Part 1" there are two buttons with visual effects "dissolve to grey". The first button "Back First Page" is used to move the user-learner from any of the content pages to the first page (card) of the stack. On each content page there is a list of subject topics. The first page of the stack "Software Part 1" includes a brief overview of the stack. The second button "Questions/Exercise" is used to move the user-learner from one of the content pages to the "Software Part 2" stack and especially to the "Questions/Exercise" part to give his/her answers.
<u>Wipe left</u>
It gave the impression of turning a page, because it revealed the next card as if that next card was underneath the first one.
<u>Scroll left</u>
A similar effect to wipe left but differed in that the next card did not appear underneath, but instead appeared to slide into view from the right as the original card slides out of the view to the left. Both wipe left and scroll left give a sense of moving forward in the stack.
<u>Wipe and scroll right</u>
Wipe and scroll right convey moving backward in the stack.
<u>Wipe and scroll up and down</u>
These give the impression of flipping through cards, index style. These effects provide kinaesthetic reminders to users and help them to orient themselves within stacks and they were used in the case of navigational buttons.

Barn door open

It gives the impression of opening a stage, a play or a window onto something else. Unlike iris open, barn door open does not indicate that the thing being opened is smaller or is in need of greater magnification.

Barn door close

It has the effect of closing a scene, being finished or going back to an entry point. For instance, in the stack "Intensity of current" there is a button called "Qualities of current". By clicking on it, you are asked "Which of the electric current qualities?". There are two answers-buttons; clicking "the first" or "the second" button the visual effect barn door open is used for the transition to something else (the first or second quality of current) while the user-learner was in the definition and the explanation card of the concept of the electric current. Barn door close is used for going back to the first card of the stack because the user-learner needs to return to the entry point.
Finally, in the "Resistance" stack checkboard visual effect was used for a better representation of the phenomenon of the flow of water in a hosepipe while clicking the "Animate !" button.

Animation

It is common sense that animated pictures of events and phenomena are powerful teaching and learning tools. Animation, the illusion of movement, was of great interest to students and also had a big impact on the students' learning of the subject domain. This was in line with other researchers' findings (Pezdek and Stevens 1984, Rada 1991). The software let students control the whole animation process by using certain buttons for interactions and in many cases users could manipulate various factors which influenced the animation process, as well.

Sound and its purpose

Sound was used to perform a variety of functions within stacks, for example to provide transitions; to illustrate content; to convey progress; to give feedback to users; to complete and integrate animations. This provided a complete environment at certain points within the stacks. Like graphics and visual effects, sound gave users a vehicle for conveying messages in ways which augmented the text of the stacks. The result being that, as the stacks were enriched and enlivened the users' experience of the stacks was kept enjoyable.
However, the sound had to be kept low so the students were able to work together in the classroom.

Sound was used for various purposes:

a) To provide some transitions like a visual effect

Users associated what they heard with what they saw. The actual use of button was learned more quickly by associating the specific button with one sound and one visual effect. Attention was also paid to making the sound for a transition to last roughly the same time as the visual effect. For example, the buttons for travelling forwards and backwards between the cards in the "Questions/Exercise" stack, was supplied by a "booing" sound effect and "wipe left or right" respectively so as to inform the users that there was a change, a new question or another subject to study.

In particular, moving between different sections within a stack or stacks the combination of sound and visual effects reinforced the users' sense of location and movement through the software and learning exploration.

Additionally, sound effects were designed in such a way as:

b) To demonstrate content, such as an illustration; because sound in an illustration demonstrated the quality or property that a stack's text discussed. It acted as a functional part of the stack and contributed not only to the content but also to the overall effect.

Examples are, the snapping marbles sound effect in the "Current in wires" stack, the imitation of animals' voices and the whole background noise of a farm in the "Voltage-Dividers-Animals" stack and the special sound of a locomotive in the "Train-Ampere" stack.

c) To inform users of progress, because it became a way to tell users that an event was happening.

d) To give users feedback about events which did or did not occur, such as in the "Questions/Exercise" stack if a student's answer was correct or incorrect, different sounds and other effects were presented on the screen. A correct answer was indicated by a flashing screen (card) while an incorrect one was indicated by a pop-up-field with the text "Terrible !!! Try again" accompanied with an unhappy sound.

e) To integrate an animation or graphic information;

f) To provide a continuous background noise like a movie soundtrack, as at times animation or graphic information were more effective.

Sound and visual images require great amounts of memory. As space was such a big consideration, another way to produce sound which used little disk space was used. Thus, HyperTalk's play commands took an active part in the composition of sounds to fit in with the content and to give fun to users to encourage them to continue.

Sound is an especially rich and fertile element to add to HyperCard stacks. The framework for its use was to emphasise the feedback to users, as displayed on the screen. It played an important role in combination with graphics and writing, so that students received an integrated and clear message of the software's purpose of teaching and learning about Electricity.

Stack Design : Graphic and User Interface Design

According to Apple Computer Inc. (1987): Human Interface Guidelines and Riley et al. (1990), the key to designing an effective stack is to focus on:
a) Who will be using the stack and
b) What the stack will do
Thus, when a stack seems simple and straightforward to the users, even if it is doing complex tasks, they perceive the stack design as effective.

Two aspects of design are especially important in building a HyperCard stack:
a) <u>Graphic design</u> : the appearance of cards and backgrounds
b) <u>User interface</u> : users' interaction with the stack and navigation within it.
Both aspects depend on the stack's users, the subject matter and the style of presentation of the stack.

Designing a stack is like designing any other software application. The list below summarises the guidelines for such a design.
<u>During the Design Phase</u>
1. Decide who are the users
2. Decide what the subject matter of the stack is
3. Decide how to present the subject matter to your users
4. Make your stack easy to navigate
5. Introduce users to the stack
6. Integrate text, graphic design and audio design
<u>During the Evaluation Phase</u>
7. Plan to change the stack from time to time
8. Test early, test often and listen to the reviewers
9. When you are finished, check the stack once more.

Guidelines of Design
During the Design Phase of the software :
<u>1. Decide who are the users</u>
Defining users is the principal factor which can help to focus the design of the stack. In this particular research, the users varied widely. Some users were familiar with computers and some had never touched a computer. Most of

them had a poor physics background with many difficulties in the area of electricity. Thus, they needed positive feedback frequently and a simple user interface. While developing the stacks of the instructional software, representative users tested the software and they suggested some improvements.

The human interface design principles are based on some assumptions about people. A good interface allows people to accomplish tasks. Tasks will vary, but people share some common characteristics. People are instinctively curious and they want to learn. They can learn best by active, self-directed exploration of their environments. People strive to master their environments; they like to have a sense of control over what they are doing, and to see and understand the results of their actions. They are also skilled at manipulating symbolic representations; they love to communicate in verbal, visual and gestural languages. Finally, people are most productive and effective when the environments in which they work are enjoyable and challenging.

The following design principles form a powerful basis for designing and evaluating HyperCard stacks. These are a simple way to make stacks more usable. A single principle, such as that of user control, can guide many decisions, from giving users buttons to control their navigation to giving them volume controls with which to vary sound (up, down, on off etc.)

a) Use of metaphors

People have more experience with the real world than they do with computers. Taking advantage of their experience, the use of metaphors in the stacks corresponds to the everyday world. HyperCard is already based on a real-world metaphor, the "card". People are familiar with using cards to organise information. The card metaphor allows users to make some important assumptions about how HyperCard works. Thus, users can assume that cards can be grouped together into stacks, that they can have both text and pictures on them and they can be changed or updated.

A book metaphor was used in the stacks. This implied that the information was presented in a linear format with movement limited to "forward", "backward" and "turn-to-given-page" and that it was possible to view all pages by simply going forwards from the beginning to the end.

The selection of this metaphor was made in the consideration of the fact that the content of the stacks of the software - in which concepts from the area of electricity were included - lent itself to the metaphor. Actually this metaphor, as a real-world one, tended to help users to understand how to use the stacks.

There was also information provided by the software, concerning its structure and its use. In addition, whenever appropriate, audio and visual effects were used to support the metaphor. At the same time, the subject domain was designed in the framework of models and analogies so that both subject and technical domains were well-matched and mutually supported.

b) Direct manipulation

This principle is based on the assumption that people learn best by active, self-directed exploration. They also expect their physical actions to have physical results and they want their tools to provide feedback. This can be provided visually, audibly or both. This principle offers options to users by providing visible choices, ways to make their choices and feedback acknowledging their choices.

For example, topics of interest are highlighted; travelling text fields are used to focus users' attention on certain specific features of some electrical concepts or applications. In the stack "Shorts" there is a special icon button - a signal of danger - which activates a highlighted travelling text field. This text field is accompanied by an alarm (distress) tune for the user-learner to be aware of the awful effects of a short in a circuit (See fig. 2-4).

c) See-and-point instead of remember-and-type

Stacks were visually and spatially oriented. The way in which text, graphics, buttons, options appear was consistent and well thought out. Users were able to anticipate what would happen when they interacted with the stacks by choosing objects, activities and options.

To avoid users having to remember possible destinations and ways of getting around the software stacks, options were kept on the screen and their use made clear. There were two kinds of see-and-point options on the screen:

1) Those which were available at all times such as the "Map" button, the arrow buttons to go forwards and backwards.

2) Those which were card specific, such as mainly buttons for interaction to animate pictures, to turn on sound effects, to activate visual effects etc. Research findings mentioned that users who are new to a stack or who are looking for potential actions in a confused moment must be able to find a desired option on the screen. Because most of the students were unfamiliar with computers and especially with the HyperCard environment, an introductory session on the above was given and "see-and-point" ways were provided by the software for them to use and navigate through the software (See fig. 2-7).

d) Consistency

Consistency within a stack is essential. The way that users do things should always be consistent within a stack. For example, the stacks of the software "Learning Electricity" had a consistent design for the following elements:

1) The graphic look
2) The grouping of buttons
3) The placement of buttons
4) The visual and audio feedback
5) The card layout
6) The background for cards with similar functions
7) The structure of the stacks.

Consistency in these elements made the software environment easier and more enjoyable to use hence the user-learner could focus on its content. The result was that students learnt the electrical concepts more effectively.

e) What you see is what you get

This principle is of special significance in stack modelling and navigation. It lets users know what they are seeing and how it relates to the whole package. A representation of the software was provided in the form of a map and students could explore the subject domain of the software in detail.

f) User control

As mentioned in section 2.1.1, the learners and users initiate and control all actions and not the computer. The framework of the software design was for the learners and users to act and the computer merely to react, and so the environment of the software was interactive, letting the learner-user choose what would happen next, both in using stacks and in navigating around them. This was especially important when offering animations and/or sound sequences.

g) Feedback and dialogue

To be actively engaged, the learner must be informed. When students initiated an operation, the software provided immediate feedback so that the operation could be carried out. Immediate feedback was usually provided by buttons which become highlighted, click, beep or display a visual effect etc. If an operation could not be completed in one step, then the software provided questions with answers from which the user could choose the desired direction in which to go. This communication was brief, direct and expressed in the students' vocabulary in both subject and technical domains.

In general the students' activities were simple; they simply had to click on buttons, either for navigation or for interaction, and type in text fields (fig. 2-5 and fig. 2-7).

h) Forgiveness

Learners do make mistakes. Acknowledging this, the software environment offered students a certain leniency allowing them to do anything reasonable and to warn them when they entered risky territory, either to back away gracefully or plunge ahead aware of the consequences. When students got lost in stacks the software helped them to find their way again. A manual was provided but as most users do not like to read manuals, help was provided at all times, by the software. Additionally, if students had completed the whole process the software allowed them to restart so that they could improve the results of the evaluation of their answers (fig. 2-5). Otherwise, they could leave the software, receiving a graceful exit, such as a text field below the results which thanked the user for his/her co-operation.

i) Perceived stability

It is of great importance for the software to provide conceptual and visual stability.

With regards to the conceptual stability, students had a consistent model of how to perceive the stacks' function and structure. Students perceived the stacks to have a single-frame, tree structure with a clear set of options and understood these options and what their roles were.

With regards to the visual stability, a consistent overall look and graphic design was provided for the stacks. The design of the card layout was constant for similar cards and visually related for all cards of the stacks. Buttons were always placed according to functionally grouped locations and their design was generally consistent.

Both conceptual and visual stability provided students with a comfortable and understandable computer environment. The illusion of stability was of importance. The environment could change as learners interacted with it. However, there were some familiar landmarks for students to rely on.

j) Aesthetic integrity

People deserve and appreciate attractive surroundings. In traditional computer applications, the visual appearance of the screen has been a low priority. In contrast, HyperCard stacks depend on the visual appearance of the screen. The main framework of the software design was a consistent and visual communication. According to recent research, this is powerful for delivering not only complex messages simply, subtly and directly in the area of the technical domain but also for delivering complex concepts, such as those in the area of electricity.

The visual appearance of the software was simple and sufficient because it came from a researcher who would like to improve student' learning of electrical concepts and not from a professional designer. The emphasis of the software design was on learning the subject matter rather than on the visual appearance of the screen.

2. Decide what is the subject matter of the stacks

The subject domain is from the area of electricity because many researchers reported sequential reasoning and other misconceptions related to the concept of electric current, potential difference, resistance and resistors in various circuits. The purpose of both subject matter and technical design of the software was to discover these misconceptions and to treat them by using the facilities provided.

3. Decide how to present the subject matter to your users

The presentation of the subject matter was influenced by both the users and the subject matter itself. Choosing a presentation method is a pivotal design decision. A metaphor acts as an identification between a real world object and parts of the software which share the object's characteristics; this helps the students learn easily and remember better.

Taking into account that the standard HyperCard interface uses the "card" metaphor users already have an experience of organisation of cards and they establish a similar organisation of the provided information in their memory. Familiar metaphors help students to grasp complex ideas. For the user interface, the technical software used a picture-book paradigm. For the subject matter, models and analogies were used to communicate concepts effectively (fig. 2-4).

4. Make your stack easy to navigate

Navigation is the most important component of the software design because as a part of the stacks' user interface, it lets the user move around within stacks. If a user is frustrated or confused while trying to move around then he/she will become despondent no matter how useful the subject matter.

To navigate effectively, students needed to know the options provided by the software. The software design focused on simple and intuitive navigation within stacks. The key point was: the less students have to think about where they were or what to do next, the more they could concentrate on the subject domain. The stacks' navigation addressed students' needs, such as context, location, destination choices and travel methods. A map of the whole

software could satisfy all of the above mentioned needs by showing the stacks' layout, using highlighting to indicate where the user has already been and providing arrow buttons which students used to travel to their next destination (fig. 2-6).
Using a real-world metaphor such as a picture book was another way to give students integrated navigation information. Visual effects were a subtle, powerful way to reinforce their navigation choices.

Stack structures

The term "stack structure" actually means perceived stack structure - the way students think of the stack. The order in which students see cards is determined by how the cards are linked, which might be different from the physical order of the cards in stacks. The focus of the software design was for the stacks' perceived structure to be simple enough for the students to navigate within stacks, even though they had different backgrounds and had studied different cards. There are linear structures, tree structures, network structures, single-frame structures and combination structures.
The linear stack structure is one which encourages a user to move through it in a straight line and provides a single logical path through the contained information. However, it is not useful when users want to be able to select different paths and branches within a stack or stacks depending on various decisions, actions or preferences.
In these cases, one of the non-linear structures can provide better navigation. A tree stack structure is one which lets users choose between several branches to follow the path which interests them. Thus, navigation in tree-structured stacks was implemented and students could move forwards and backwards within a branch, return to the most recent forking point, return to start and possibly jump back to the whole software map. Students mentioned that they could keep track of the stacks and they did not get lost.

Aids to navigation

As mentioned above, users need to travel around and must do so without getting lost or confused. To facilitate successful navigation, the stacks design concentrated on the stacks' layout, means of travel, available destinations and the current location to be easily identified by learners. All of them were provided with a combination of devices and graphic elements. Actually, the general environment of the stacks which was represented as a picture-book metaphor provided the framework for students' navigation. Some common navigational elements were used, such as menus, metaphors, textual reminders, stack names, "you-are-here" or location indicators and travel buttons.

a) Menus

Menus were topics lists of topics and contents and provided both the content and ways in which students could measure their progress in their exploration of the whole software. The term "menu" is in this case being used here loosely to refer to any list of stack sections. It is typically a main screen containing text and visual labels for various and different sections of the stacks. Students see the menu early and return to it frequently to orientate themselves and to navigate through the rest of the stacks. Generally, the menu roughly mirrored the stacks structure and listed all the main parts of the stacks. Because the whole software section itself contained a number of topics, submenus at the beginning of each section were also used to facilitate navigation.

In fact, two types of menus were used: the text-only menu and the text-and-graphics menu emphasising text.

The first one relied solely on text to inform students about the sections of the stacks. A special consideration when designing this kind of menu was to make sure the user knew which words on the screen related to each button. The written instructions also advised the students what to click on to. Emphasis was given to providing graphical clues as well, by making clear buttons shapes, such as the standard rounded rectangle HyperCard button shapes, around each menu word; by using a distinctive typeface for many button names; by providing a symbol next to the menu word. Generally, there was some designation which invited interaction (fig. 2-7).

Menus were useful because the stacks contained some natural topic groups, such as different subject headings, branches and other kinds of information. They were appropriate because the information provided was not layered too deeply and had a simple tree-structure connection.

b) Stacks map

The map was a powerful navigation component because it satisfied many users' needs at once. It differed from menus in that the map provided a visual representation of both the software pieces and the connections between them. Additionally, the map was "live" because users not only looked at the map but could also interact by clicking onto areas so as to travel to a chosen point. The map was especially useful because of the tree-structure. Thus, the map of the whole software presented the contents, structure and linkage of the stacks. This fact facilitated navigation and learning because it was easy to locate any topic in relation to the rest of the others. At the same time a qualitative relationship between concepts from a subject domain was formed in students' minds.

c) Metaphors

Generally, real-world metaphors help convey navigation options. The stacks structure imposed the chosen metaphor for navigation. Tree-structures are usually modelled by organisation of stack maps and books with different sections or chapters and subheadings. As mentioned, a picture-book metaphor was used and additionally the graphic images furnished more information about how the subject matter was laid out and how it could be traversed. In many cases, mainly in subject areas included in the theoretical feedback, there were animated pictures, visual and sound effects to attract students' interest and to motivate their exploration for learning through the software. The subject domain also had an influence on the choice of the models and analogies used in the area of electricity.

d) Textual reminders

Because of the tree-structure of the whole software, in some cases textual reminders were used to call attention to certain buttons, either for navigation and/or for interaction. A textual reminder lessens the amount of detailed information that users had to remember in order to use all of the stacks so that they concentrated more on the stacks' content.

e) Stack names

An effective way of letting user-learners know where they were at any given point was to use names which identified stacks. The names in combination with the "map" card, defined users' location within the whole software and contents of the subject matter.

f) "You-are-here" or location indicators

A good way to reinforce navigation was to provide both context and location information simultaneously. The map, for instance, indicated "you are here" and the relevant buttons were highlighted for either returning to or leaving the map. At the same time these were users' progress indicators (fig. 2-4).

g) Buttons : letting users' travel

Whenever users need to move through the software, buttons were provided to act pleasantly and effectively. Buttons were designed to let students travel, for example forward or backward (buttons for navigation - navigational buttons) and to let them do other things, such as initiate animations and sound effects etc. (buttons for interaction- card specific operational buttons). The first type of buttons had a different appearance to the second type. By making travel buttons consistently different, not only in appearance but also

in location, users did not have to figure out that there were different categories of buttons.
Additionally, not only the placement but the graphic design of buttons were used to differentiate between both types of buttons. Arrows were used for the first type. Pictures with or without specific words, were used for the second one. With regards to the design of buttons and their role in the software, further details were provided previously, in this chapter (fig. 2-4 and fig. 2-7).

5. Introduce users to the stacks
The most important elements to introduce to users the software were how to use the stacks, how to navigate through the whole software and how to get further help. An introduction -such as "About the software" and "How to use the software" stacks- was provided to give the uncertain novice user the information necessary to feel confident using and exploring the rest of the software.

A concise overview of the stacks' content in the form of a map was also provided to teach the whole software structure and help the user navigate and learn through this kind of exploration. Acting as a basic reference point, the map was another way to orient users to the whole software quickly, because it was a known place from which users could get to other destinations, to both technical and subject domains. It was a single primary point which gave users a single model of how to use the software.

Additionally, menus were used as secondary priority reference points for an exploration in depth of the subject domain (first page of the Software Part 1 and first page of the Questions and Exercise in the Software Part 2).

6. Integrate text, graphic and audio design
In this final point of the design phase, emphasis was given to both text and audio-visual elements working together so that they gave a consistent message and users received an integrated stable impression of the software in both subject and technical domains.

During the Evaluation Phase of the Software
Developing the software package was a cyclic process of designing, getting reviews and revising. Most of the time was devoted to the process of designing by following the main guidelines, as mentioned above. However, enough time was spent on the evaluation phase which consisted of getting reviews and revising the package.

This phase was divided into steps:

7. Plan to change the stack from time to time

This happened not only at the end but also during the design phase, after completing a topic or a larger part of the software which came from a combination of smaller parts.

8. Test and listen to the reviewers

Reviewers' comments could help to integrate the software design and to make it "perfect". There were two types of reviewers: educational software developers and students with good experience of HyperCard techniques.

9. When you are finished, check the stack one last time

2. 1. 3 e17) Generic Learning Tools and the Development of Learning Environments

The use of generic tools in education shows their merits and their flaws. On the one hand, these tools increase the interaction between student and computer.

On the other hand, certain flaws reduce their effectiveness in teaching & learning. Regarding:

1) The access to knowledge

The software, as is the case for all generic software, usually supports specific knowledge representation and access mechanisms which are not suitable for certain fields of study. In HyperCard, the screen can display only one card at a time and the designer is required to fit all the information into a limited space. Moreover, HyperCard and most generic tools provide software, which is difficult and complicated. This can hinder their potential beneficial impact on the learning process.

2) The type of knowledge

HyperCard, Hypermedia systems, spreadsheets and data bases provide only factual knowledge processing. Consequently the learner cannot operate on other kinds of knowledge, nor use them to generate new knowledge in the subject domain. For lasting acquisition of factual knowledge, it is important to integrate facts into a network of concepts which use the facts. To be able to operate on more complex forms of knowledge, the systems required are beyond usual databases ones. The construction of systems which can process all kinds of knowledge depends on techniques being developed in the field of

Artificial Intelligence [O'Shea and Self (1983), Elson-Cook (1990), Moyse et al. (1992), Khan and Yip (1996), also see p. 308].

2. 1. 3 f) CONCLUSION : To a New Generation of Learning Software Tools

The study of the strengths and flaws of the actual software can be summarised as:
1) Students have access to the knowledge domain which can be extended by their use of the software.
2) They obtain presentation and processing tools.
3) They obtain support at different phases of their cognitive activities, and advice for the use of these tools.
4) Using the modelling form of knowledge they come into cognitive conflict which causes to changes in the knowledge domain.
5) Interface and tools, such as HyperCard, are closer to natural mental operations than other database systems.

In this thesis, the researcher not only chose the learning software tools but also as a designer adapted these tools to the subject domain of electricity, taking into account pedagogical strategies and age of the students.

2. 2 SUBJECTS

The sample consisted of 30 University students.
Twenty two of them were in their first year of the Bachelor of Technological Education degree (BTechEd). These students were taught the topic during their lectures in the Department and did some laboratory work in October.
Three of them were fourth year students of BTechEd and had already passed the first year exams on electricity and also had a good background in computing and HyperCard techniques.
Five of them were second year students of the Dept of E & E Engineering who had also already passed the first year exams on electricity and also had a good background in computing. In the latter two cases, a reminder session on electricity was also provided.

All students had also passed the National exams and generally had a satisfactory level of knowledge of physics.

An introductory session on HyperCard techniques and the use of multimedia was provided to all students, as the basis for better human-computer interaction. Special feedback on HyperCard techniques was also offered by the software, as mentioned above.

2. 3 DESCRIPTION OF THE LEARNING ELECTRICITY SOFTWARE

"Learning Electricity" is an instructional software package including topics such as current flow, potential difference, resistance, resistors in series and in parallel and Ohm's law. It consists of two parts:

a) Software Part 1 (Theoretical feedback on the above topics);

b) Software Part 2 (Ten questions with multiple choice responses and one exercise).

A detailed map is included for a better overview of the software (fig. 2-6).

2. 3. 1 How to use the software

Students can start <u>either</u> from the "Software Part 1" (Theoretical Part) and go to "Software Part 2" (Questions and Exercise) - which is suggested as a better place to start - <u>or</u> from "Software Part 2" and, after facing difficulties in answering some questions, go to "Software Part 1" for more help.

To become familiar with "Circuit Symbols", the lexis of physics and technical terms students can refer to the relevant topics in the actual software (fig. 2-6).

2. 3. 2 The role of buttons

There are buttons for navigation and for interaction. Their use is essential. The appearance of a button (either a label or a figure) offers students the opportunity to discover its actual use (See fig. 2-4 and fig. 2-7).

The buttons for navigation are to go to:

a) previous card (go back)

b) next card (go on)

c) the map

d) a certain content page

e) the first page of the Software Part 1

f) the first page of the Questions/Exercise

2. 3. 3 Navigation through the "Learning Electricity" Software

2. 3. 3 a Title

When students click on "Title", then it is highlighted and the picture presented on the screen introduces them to the main of topics that they are to study (e.g. resistors, current, potential difference etc.).

There is an arrow button (to the right) to transfer students to the next card. The "Map" helps them to have an overview of what exists in the Software. Students can go to the "Map" from every part of the software.

2. 3. 3 b Stacks Folder

2. 3. 3 b1) About the software

The next step is the stacks folder. Students can move to this step either by clicking on this button or by clicking on the arrow button (to the right). They then can observe that the "About the Software" button becomes highlighted and they can transfer to the relevant stack. Entering this stack students can see the buttons "Software Part 1", "Software Part 2" and "Evaluation" are highlighted in order to emphasise the main structure of this software. Thus, they can understand the navigation procedure. By clicking on each of the three buttons, they can go to the relevant stack and return.

When students click on the left arrow button (to go backwards) the "Map" button is highlighted, they can then transfer to the "Map" card. When they click on the right arrow button they process to the next step which is the "How to use the software" stack.

2. 3. 3 b2) How to use the software

This is the next stack which explains to students how they can pass through the instructional software by using navigation and interaction buttons. They can get more details on the buttons either by clicking on the "Click me!" button or on the right arrow button. The next card categorises the two kinds of buttons which are used in the software. Going on to the next card the navigation buttons are shown on the screen. If students click on one of them they can see a travelling text to remind them that these buttons are inactive. The next card includes the interaction buttons. However, neither these work! Their purpose is to help students become familiar with them.

2. 3. 3 b3) Software Part 1

Software Part 1 includes topics such as current, potential difference, power, resistance, resistors, short circuits, switches, models and analogies on electricity. The software provides another way of teaching & learning these concepts through models and analogies. The models and analogies provide students with the opportunity to talk and exchange their ideas with other students or the researcher for further understanding of these abstract concepts. Often the models and analogies provided are in conflict with the students' ideas. As a result of this a useful discussion starts between students and the researcher (or the teacher) which often helps students to establish the correct relevant model in their mind.

By clicking on buttons students can obtain further information from pop-up-fields which appears on the screen. When they finish, they can click on the pop-up-fields so the information disappears from the screen.

By pressing on the right arrow button to go on, the "Map" button is highlighted and students move to the "Map" card. The Software Part 1 button is highlighted and activated, so students can transfer to the first card of the Software Part 1 stack. This card includes the relevant topics for answering the questions and for doing the exercise of Software Part 2. These topics are:

a) Current
b) Potential Difference
c) Resistance/Resistors
d) Power
e) Short Circuits
f) Switches
g) Models and analogies in Electricity

By clicking onto one of them the relevant button is highlighted and students are transferred to another card of the Software Part 1 in which a list of subtopics is included. By clicking onto the required subtopic they can be transferred to the relevant stack for further details. If they are in the card "Models and analogies on Electricity" and click on a model (e.g. voltage dividers model) then they obtain an animated picture of it and a text field appears to remind them to press the "Back" button so as to return back to the previous card. There are also two other buttons: "Back First Page" and "Questions/Exercise". The first transfers students to the first card of the Software Part 1 in order to choose a topic that they need, and the second one transfers students to the second card of the Software Part 2 stack in which they can move to each question or the actual exercise.

(I) **T o p i c : C u r r e n t**

I. a. CURRENT IN WIRES (stack)

I. a.1 MORE ABOUT THE ELECTRIC CURRENT (stack)

I. a.2.a MAKE CURRENT FLOW 1 (stack)

I. a.2.b P.D. OR BATTERY: ENERGY SOURCE (stack)

I. a.3.a WAYS OF CURRENT FLOWING (stack)

I. a.3.b MAKE CURRENT FLOW 2 (stack)

I. a.3.c CONVENTIONAL CURRENT/SPEED ELECTRONS (stack)

I. b. INTENSITY (or SIZE) OF ELECTRIC CURRENT (stack)

I. b.1TRAIN-AMPERE(stack)

I. b.2 AMMETER (stack)

I. b.3 QUALITIES OF CURRENT (stack)

I. b.4.a CURRENT AT A JUNCTION (stack)

I. b.4.b MORE THE EASY WAY (stack)

I. b.4.c CALCULATING FRACTIONS (stack)

CURRENT IN WIRES (stack)

By clicking on the subtopic "Current in wires" from the topic "Current" of the Software Part 1 students can enter the first card of this stack. This is an introduction to the electric current topic, just as a flow of electrons. By clicking on the right arrow button they can progress further through this subject.

The second card "The mysterious marble" identifies the current as a flow (transference) of energy by giving an analogy of snapping one or more marble(s) against one end of a row of marbles. On the bottom of this card, there are four buttons on which students can click onto for further details.

Therefore, by clicking onto the:

a) SNAP !!! button, students see an animated picture of the above mentioned analogy. After that, an answer box is shown on the screen. By clicking on the "speed" button they are also asked to identify the speed (higher or lower). Thus, by clicking onto the button of their choice students can see the marble rolls and stops at the first marble of the row, then see the last marble rolls. Following this a message appears on the screen asking the students to click onto the button "Try again" while the three other buttons (Snap !, Speed, Marbles) have already disappeared. Students therefore return to the first situation so they can repeat this activity. The three hidden buttons are then revealed again for students' experimentation.

b) MORE ABOUT THE ELECTRIC CURRENT button: students are transferred to the synonymous stack. This is an anthropomorphising model of current. The "Click me !" button animates the picture.

c) MORE ??? button: students are transferred to the MAKE CURRENT FLOW 1 stack which represents the cause of free electron movement. The "battery" button shows a pop-up-field with more details in it. The "Click me" button displays the concrete and simple representation of the role of a battery (or pd.), in transferring a certain amount of energy to every charge of 1 Coulomb (in the PD. OR BATTERY: ENERGY SOURCE stack).

d) WHICH WAYS ? button: students are transferred to the WAYS OF CURRENT FLOWING stack. By pressing the top button, the scientist in the picture is shown to be questioning himself about the direction of current left to right or right to left? At the bottom left, there is a balloon button called "Real Current". By clicking onto it, students are transferred to the MAKE CURRENT FLOW 2 stack. The "Direction of current" button animates the flow of current. At the bottom right, there is another balloon button called "Conventional Current" which transfers them to the CONVENTIONAL CURRENT/SPEED ELECTRONS stack. The scrolling field of this figure gives details as to how scientists accept the electric current direction as opposite to the electrons. The second card of this stack calculates the low speed of the free electron movement through a metallic conductor and supports the previous concept of the electric current as a flow of energy through a conductor. The "Guess!" button activates a pop up field in which the speed of free electrons in a copper wire is calculated. Then, the "Solution" button shows another pop-up- field which proves that the electric current is a transference of energy from one point to another in a conductor and that this is nearly immediate.

By using the relevant buttons students can always be transferred to the initial starting point. Clicking on the left arrow button they move to the intensity of current (or size of current) stack.

INTENSITY OF ELECTRIC CURRENT (or SIZE OF CURRENT) stack

In this stack, there is an analogy between one Coulomb of charge and each small wagon. Thus, the man measures how many wagons pass under him each second or how many Coulombs per second or how many Amperes. If students click on the finger button they move to the "TRAIN-AMPERE" stack in which a simulation of the wagon's movement takes place, while the man counts the number of wagons per second passing under him. At the bottom, there are three buttons. These are:

1) The "AMMETER" button which is linked to the relevant stack. When clicking onto the Coulombs and Amperes buttons, pop-up-fields are shown, for the above units' definition. The button which looks like a light bulb presents three pop-up-fields which gives more detail and explain the relationship between Coulombs and Amperes.

2) The "QUALITIES OF CURRENT" button is also linked to the synonymous stack including the conservation of charge and Kirchhoff's first law. An answer box appears and students are asked which of the qualities they would like to study.

3) The "CURRENT AT A JUNCTION" button enables students to move to the relevant stack. At the top left, there is a button which animates a picture which presents an analogy to the current at a junction (anthropomorphic model). Another button (question mark) transfers students to the "MORE THE EASY WAY" stack. By clicking onto the "Example" button there is an animation of the current flowing through the branches. For more information students can click on the "CALCULATING THE FRACTIONS" button. Three examples are given with reference to the division of current according to the resistors of each branch. The "MORE EXAMPLES" button displays an answer box for students to choose which examples they prefer. They can discover methods for the easy calculation of current at a junction by pressing the question mark button at the bottom of the card for each example.

II. Topic: Potential Difference

POTENTIAL DIFFERENCE (stack)
II. a.1 GRAVITATIONAL MODEL 1 (stack)
II. a.2 GRAVITATIONAL MODEL 2 (stack)
II. a.3 HYDRAULIC MODEL 1 (stack)
II. a.4 HYDRAULIC MODEL 2 (stack)
II. b. VOLTMETER 1 (stack)
II. c.1.a VOLTAGE DIVIDERS (stack)
II. c.1.b VOLTAGE-DIV-ANIM (stack)

POTENTIAL DIFFERENCE (stack)
The stack represents the pd. as the energy per unit of charge transferred between two points A, B on a line AB. There are 5 buttons on this card.
By clicking onto:

The "MORE ?" button: students can see a pop-up-field which provides more information on what pd. is and what its unit is. At the bottom of this field, the message "Click me to disappear !" reminds them students of what they would need to do.

The "MUCH MORE ??" button gives the essential and basic models which are used for teaching and learning this concept. By clicking on it, students are asked to select either hydraulic or gravitational models.

By pressing the "hydraulic" button, they can see the two following models:
HYDRAULIC MODEL 1 (stack)
This stack represents an analogy of the pd. as a difference of the hydrostatic pressure between two points of water flow. In the middle of the figure, there is a question mark button which gives students a pop-up-field (scrolling left). This is located below and explains the figure. They can click on the pop-up-field to make the explanation disappear, as mentioned in previous cases.
HYDRAULIC MODEL 2 (stack)
This is an animated picture explaining that the pd. (or a battery) is a transformer of energy in a circuit. By clicking onto the balloon over the girl's head, students can see the whole process of this event and a pop-up-field showing the girl's conclusion. They can see that the pd. gives energy to every unit of charge and that is the flow of current inside a conductor.

By pressing onto the "Gravitational" button, students can see the following two models:
GRAVITATIONAL MODEL 1 (stack)
The stack is a simple simulation in which students can have an analogy between gravitational potential difference and electrical potential energy. Through pop-up-fields both buttons "MORE ?" and "MUCH MORE ???" give further details on the subject. The "START !" button is used to repeat the simulation.
GRAVITATIONAL MODEL 2 (stack)
The stack also stresses the importance of the energy in the role of the pd. in a circuit, through an analogy of a machine which raises water from a lower to a higher potential point. The button "!" at the bottom of the field also emphasises the pd. as a transformer of energy. To avoid misunderstanding in this text field there is a clear distinction between the incorrect view that pd. (or a battery) is a source of electric charge and the correct view that it is a source of energy.

The "VOLTMETER" button transfers students to the synonymous stack and demonstrates how they can connect a voltmeter in a circuit. There is a "VOLTS" button below the text field which gives the equivalent of the pd. unit.

The "QUALITIES" button transfers students either to the first or to the second potential difference qualities (properties), since they have already been asked to select one of them before.

The "MORE ABOUT VOLTAGE ???" button transfers students to the "VOLTAGE DIVIDERS" stack, for a simple explanation of how the pd. drops as the current passes through one or two components. The second card introduces students to the meaning of voltage divider. The third card gives an analytical calculation on how much the pd. is dropped by two components (resistors) by using Ohm's law. The "HINTS" button helps them by presenting the relevant formula and the "SHOW SOLUTION" gives the whole calculation. Clicking on the right arrow button at the bottom of this card (or the "MUCH MORE ???" button) students can be transferred to another stack "VOLTAGE-DIV-ANIM" which is also a simple simulation of a voltage divider. Clicking onto the "MORE EXPLANATION" button a pop-up-field (scrolling) gives more details on the above simulation.

At the base of this card there are the three essential buttons: the "MAP" button to go to the Map/contents, the left arrow button to go back to the previous topic INTENSITY OF ELEC CURRENT and the right arrow button to go to the next topic RESISTANCE.

III. Topic: Resistance

III. a. RESISTANCE 1 (stack)

III. a.1.a Ohm's Law (stack)

III. a.1.b Ohm's law (stack)

III. a.2 $R=Rf(\theta)$ (stack)

III. a.3 $R=\rho l/S$ (stack)

III. b. Add resistors (stack)

III. b.1 Resistors in Series (stack)

III. b.2 Resistors in Parallel (stack)

RESISTANCE 1 (stack)

The stack introduces the concept of resistance as the way that a substance opposes the flow of electrons. Through the "Animate !" button students can obtain an animated picture of a hosepipe in which the flow of water is being resisted. The "MORE !!!" button gives them the three basic formulae for resistance [Ohm's law, R=pl/S, R=f(θ)] within relevant pop-up-fields. Students also can obtain more information by clicking onto the finger button.

OHM'S LAW (stack)
Clicking onto the balloon button over the head of the scientist reveals how various resistors such as copper wire, bulb (filament), diodes follow the law. The "EASY TO REMEMBER" button present the law in a triangle and by clicking onto the "ANIMATE !" button students learn how it works.

R=pl/S (stack)
The stack is a simple presentation of the formula by the use of analogies (simple and concrete figures). The categorisation of substances in conductors, semiconductors and insulators is presented through animated cartoon pictures (anthropomorphic models).

ADD RESISTORS (stack)
In this stack students can choose one or two resistors to be added to the circuit by pressing onto the "ADD" button. Once they have made their choice, they are transferred to another card. Two pictures are shown and students can compare the brightness of the bulbs. The "MORE EXPLANATION..." button transfers them to another stack in which an analogy is presented through an animated picture.

IV. Topic: Power

IV. a POWER (stack)
IV. b Proof of El. Power Equation (stack)

POWER stack
The stack introduces the concept of electric power as the energy which is converted each second by the conductor. If students click onto the balloon button which is just above the head of the scientist a pop-up-field shows them how to create the well known formula P=VI. If they click onto the "More !" button below the picture they are transferred to the "PROOF OF ELECTR POWER EQ" stack.

PROOF OF ELECTR POWER EQ stack
The stack is an analytical explanation of the equation P=VI through an animated picture.

V. Topic: Short Circuits

SHORT CIRCUITS (stack)

The stack explains that a short circuit is the easier route for the current to flow through than any other resistor(s). The "MORE !" button transfers students to the next card where they are informed about the bad results of the existence of shorts in circuits. Clicking the "!" button they can see a text passing through the screen with a warning sound informing them that shorts are in general dangerous. The "Much More !!!" button gives an animated picture which is a simulation of a short as a race of people who prefer the easier route although this is in fact longer (anthropomorphic model).

VI. Topic: Switches

SWITCHES (stack)

The stack gives an analogy of the switch as a break of the current and emphasises this through a picture of a flow of people stopping in the next card.

2. 3. 3 b4) Software Part 2

This consists of ten questions with multiple choice responses and one exercise.

Clicking onto the "Try!" button or the right arrow one, students are passed to the second card of the stack. There are buttons for the ten questions and the exercise. There is also the "BACK First Page" button which transfers them to the first card of the Software Part 1 stack from where they can choose the required topic (theoretical feedback). If students click on the right arrow button an answer box appears and asks them to select either to stay in the same stack or to go on. Pressing onto one of the questions, they can enter the "Questions/Exercise" stack.

(I) Questions

There is the "Finished" button which controls all the students' actions. The button is "responsible" for counting their answers as correct, wrong or missed.

For example, consider that a student chooses Question 1.a. He/she is asked if he/she is a "New User" or "Existing User". In this stack, each of his/her responses is added to the number of the correct, missed or wrong answers. By clicking on the "New User" any pre-existed response is deleted and the counting starts again. In this question, a student needs to choose one out of three answers. If he/she is correct the card flashes and a text field appears with a happy message such as "Congratulations!! Well Done!" to reward his/her attempt(s). Otherwise, three beeps accompanied with a text field message "Terrible! Try again" encourages him/her to "have another try". Each of his/her activities is controlled by the "Finished" button.

In answer the questions, a student can obtain feedback either from the "Hints" button (minimal help) or from the theoretical part in which he/she can find much more help than what is provided by the "Hints" button. This help comes in the form of animated pictures and modelling. The hidden button "Show Solution" appears when a student has already clicked onto two out of three or three out of five answers. In this case, he/she is also asked to write down why he/she has selected a certain answer in a particular field ("Why do you say that?").

The "Hints" button activates a pop-up-field for some help. If a student feels that he/she needs more, then he/she just clicks on the left arrow button so as to be transferred to the second card of the Software Part 2 stack and from this card to the first card of the Software Part 1 to select the topic that he/she needs.

As mentioned above, the "Finished" button is an essential one. If a student forgets to click onto an answer, this button will reveal an answer box to remind him/her to do so. If he/she has already had one (or two) attempt(s) then the "Finished" button reminds the student to try again. Otherwise as previously mentioned three beeps and a text field with the message "Terrible! No more chances" appears on the screen, acting as a reference.

During all the above attempts the "Show solution" button was hidden, as mentioned above. If a user clicks onto the "Finished" button he/she is asked if he/she "still write(s)" or he/she will go to the "Next problem" (next question) and so the student can be transferred to the next card. His/her responses have already been taken into account for evaluation. The procedure for each question is the same as in Question 1.a. However, in the exercise there is a difference. Instead of a "Next problem" button there is an "Evaluation?" button because an assessment (evaluation) of students' answers is followed after the completion of both questions and the exercise.

The student needs to avoid the use of the right arrow button because his/her answer is missed although he/she gave a response. He/she cannot use the arrow keys to go backwards or forwards.

(II) Exercise

The exercise includes a spreadsheet to improve learning about databases and includes graphics in relation to Ohm's law. In this exercise students are asked to give values to one of the variables and by clicking onto the "Calculate" button they can see the results on the screen. Students can go to the next card, where all their values for the variables (V, R1, R2, Rtot, i and Vab) are displayed on the screen. They can then click on the "Graph Info" button so as to see what they need to do as the next step for the exercise and "Graph Help" if needed. Clicking onto the "Graph File" students can open the application Cricket Graph on the screen. The "Exercise Figures" data file is displayed and they can choose the variables to plot the required graphs. When students finish all their graphs, they print them and return back to the previous card and write down their observations in the pop-up-field shown. If students click onto the "Finished" button then they are asked if they still want to write or go for evaluation.

By pressing onto the "Evaluation?" button they can go to the next card to see what they have already done. They are also asked if they have finished with the exercise. After that, students can see how many questions are correct, how many are wrong and how many have been missed. Thus according to their results one of the four faces is highlighted, with the relevant message. Students are then asked if they want another try. If their response is "Yes" they return back to the "Title" stack to start. If they click onto the "No" button then a pop-up-field appears to express the researcher's thanks for the students' co-operation and finally passes them to the "Evaluation" stack.

In the second card of the Software Part 2, there is a right arrow button. If students click onto this, they are asked if they have done all the questions and the exercise. Clicking onto the "Yes!" button also transfers them to the "Evaluation" stack.

After completion of the graphs students can retrace their steps to the previous card. They can click onto the "Observations" button and write their observations and explanations on the graphs. They need to print them either by clicking onto the "Print" button or the "Finished" button.

In the second case, they are asked "Still Write" or "Evaluation ?".
If they click onto "Still Write" they stay in the card to finish their writing.
If they click on "Evaluation" then the card and the text field related to their observations on the graphs are printed and students proceed to the

evaluation card, where they can see how many of their answers are correct, how many wrong and how many of them are missed.

Students are asked if they are "New User" or "Existing User" when they open the stack "Questions/Exercise"; enter one of the questions and the exercise, or on leaving the stack. The answer controls the number of the correct, missed and wrong answers. Clicking onto the "New User" any existing answer is deleted and a new count begins. There is no change on the counting of their answers (correct, wrong or missed) if they click on the "Existing User".

During their work on answering the questions students can go to the theoretical part (Software Part 1), study subject that they think that they need to study, and return back to the question that they were at before.

2. 3. 3 b5) Evaluation

This is a reminder of students' work mainly on "Questions/Exercise" of the Software Part 2. They can try again or they can have some more information from a pop-up-field presented below by clicking on the "Not Really" button. Pressing the "Yes" button indicates they have finished and they go on the "End" stack.

2. 3. 3 b6) Circuits' symbols

This acts as a reminder to students of some essential symbols that they came across the "Questions/Exercise" stack.

2. 3. 3 b7) Going further

This stack is just a source of references enabling students to study both technical and subject domains (Electricity, HyperCard and Cricket Graph) in detail.

2. 3. 3 b8) End

This stack is simply to inform the students that they have finished. Even after a simple navigation through the software, with poor results, they become familiar with the terms and the concepts.

2. 4 PROCEDURE

2. 4. 1 Evaluation Framework

Evaluator	Software	Student
ASK		**ANSWER**
Goals		Anticipated Objectives Outcomes

Table 2-4
Evaluation framework

In the instructional software, evaluation takes place in both human-computer interaction (technical domain) and learning of the specific topics of Electricity (subject domain) by using tests and questionnaires. The performance or cognitive behaviour of the students is studied by tests and their attitudes by questionnaires.

2. 4. 2 Methodologies

Fundamentally comparisons between pre-test and post-test, post-test and delayed-post test, and pre-test and delayed-post test situations of students learning about electricity are studied to discover the effectiveness of the software on their learning and whether it helped them to understand the electrical concepts better by using models and analogies and the other facilities provided. Thus one can come to a conclusion on their performance in the subject domain. Additionally, after having completed all of their work with the software, questionnaires were administered to gain information on their attitudes while using the software.
For the evaluation of the teaching package, the following methodologies were used:

a) Questions / Exercise (Pre, Post and Delayed-post Tests)
To address the main directions of students' reasoning (Blease and Cohen 1990, Cohen and Manion 1989).
This consists of three phases:

Pre-test Phase

Questions / Exercise Part 1 (Students' profile before: Pre-tests)

This is in the form of a paper-and-pencil test (worksheets). Students answered the questions and did the exercise after having been taught about Electricity during lectures. As mentioned previously, help was available from Physics reference books which were available to students during their test to assist them to answer questions. Their written papers (worksheets) were used as pre-tests.

During this phase of evaluation, interviews and think aloud techniques were used to obtain further details on students' answers.

Post-test Phase

Questions / Exercise Part 2 (Students' profile after: Post-test)

This is done using the instructional software's form, including the same questions but enriched by the instructional software feedback (simulations and animated pictures). Students used the software to answer the questions and did the exercise one month later, in November. Because it was essential for students to use the theoretical feedback provided by the software, the researcher tried to persuade some of them to use it. The printouts were used as post-tests for the analysis of data.

Delayed-post test Phase

Questions / Exercise Part 3 (Students' profile after: Delayed-post-test)

This is in the form of a paper-and-pencil test (worksheets). Students were taught the subject domain in October. They answered the questions and did the exercise at the end of March. From October up to March they did not have any lecture or laboratory practice or any other activity in this domain. Again help was available to these students who needed it, in the form of reference books. Their written papers (worksheets) were used as delayed-post-tests for the analysis of data.

b) Questionnaire

The use and the effectiveness of the software was also evaluated by students answering a special questionnaire, after having completed all of their work with the software.

c) Interviews (semistructured) and think aloud techniques

While working on the Questions and Exercise, with and without the use of software, interviews and think aloud techniques were used:

1) To obtain further information on students' learning of the subject domain

2) To discover and to study students' cognitive strategies, problem-solving, imaginative, creative skills and detailed reasoning (Blease and Cohen 1990, Cohen and Manion 1989).

d) Observations (participant observer)

Students were observed to study their cognitive strategies (problem-solving, imaginative, creative, reasoning skills in details) (Strauss and Corbin 1990 & 1997, Patton 1990).

During the observations, interviews took place to support the data analysis in both subject and technical domains. Additionally, lecturers were also interviewed in order to obtain background information on their students.

The Pre-test data was categorised according to different students' conceptions and models (students' profile before). The rest of the data was used to find out students' profiles after the use of the designed software.

Comparing these profiles we can find out :

a) If any conceptual change in learning about electricity took place;
b) How the designed software facilitated this change;
c) What kind of skills students developed;
d) What kind of cognitive strategies students developed;
e) How this software worked out as a teaching & learning tool;
f) How much the teaching & learning process was facilitated;
g) How much the design principles motivated students' learning and under what framework.

Design of teaching packages is not based on the knowledge of the designer. It is enough for basic design guidelines to be followed therefore the software to become the core for problem-solving activities while interaction among students (in the form of peer interaction, peer tutoring), and between students and teacher, are in the form of human interaction. The factor which really improves students' learning, permeates real conceptual change, makes ideas explicit, is the development of communication skills by hypothesising, testing of ideas, and discussing conflicting opinions.

From all the above mentioned the designer of educational packages must cooperate with teachers for the creation of certain instructional software. This is one of the issues which not only derived from this particular research (see later on Chapter 5: Conclusions Recommendations), but was also pointed out in Bork's (1993) relevant article.

Limitations of evaluation

a) Lack of permission to collect audio/video material

It was the researcher's intention for process data to be collected through audio and videotape recordings. This became impossible because of lack of the students' permission so the data were collected mainly through the researcher's notes.

b) Lack of another independent observer being present

In similar research, reports of two participant observers are usually studied. The researcher intended to use a person who could be a lecturer/teacher of physics with experience in students' difficulties in the subject domain and not within their teaching environment.

Initially, the selection of the second observer focused on a lecturer or a member of staff from another Department and later on a teacher of physics from secondary education.

However, the students were attending lectures, workshops and tutorials; lecturers/teachers and other members of staff were employed in various activities. Limitations not only on students and lecturers/teachers but also on laboratory availability at the same time forced the research to be undertaken in one three hour session. Therefore, it was an unattainable target and was not possible for another independent observer to be present.

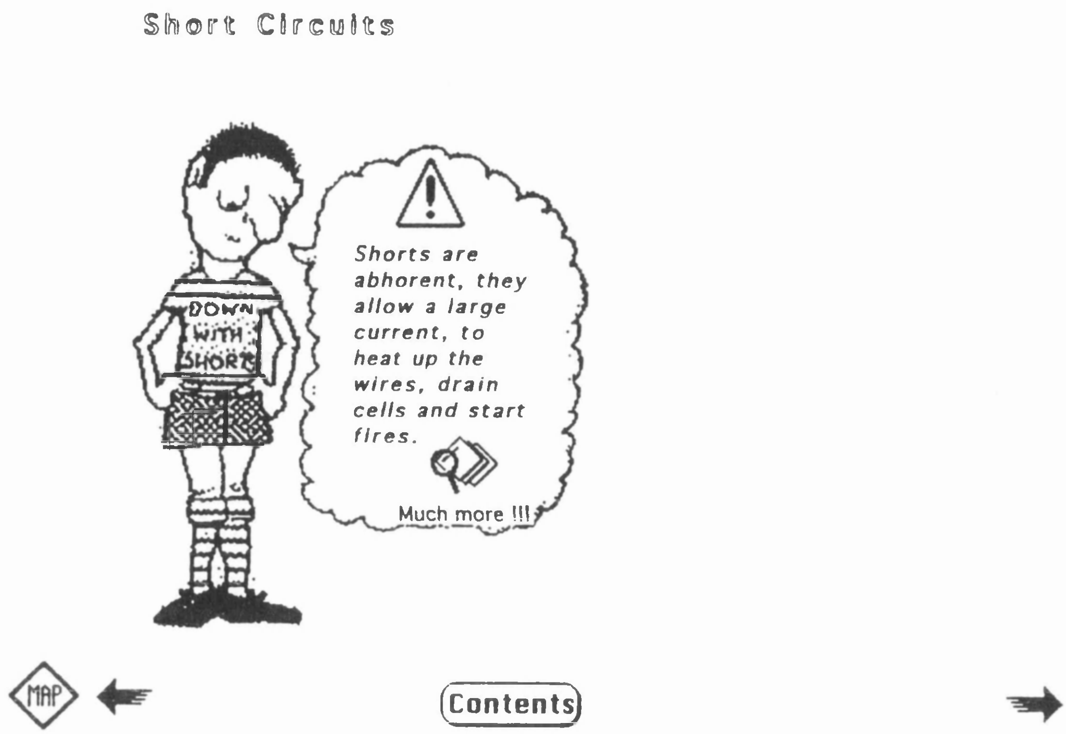
c) Decision not to use a control group

A control group was not used, as it was unnecessary and also was regarded as unethical by the class teacher. In line with the literature of similar studies, the researcher examined whether the instructional software enabled the students to improve their own learning of basic electrical concepts by comparing the students' own cognitive profile before and after the use of the designed software.

2. 4. 3 Sample characteristics

In general, the sample of subjects was heterogeneous with reference to students' Physics background. This was one of the reasons why the software included essential concepts on electricity.

As mentioned above, students had passed general exams in Physics (electricity). They had also been taught the subject during University lectures. They had enough experience of computers in general. An introductory session on HyperCard and multimedia was offered to them.



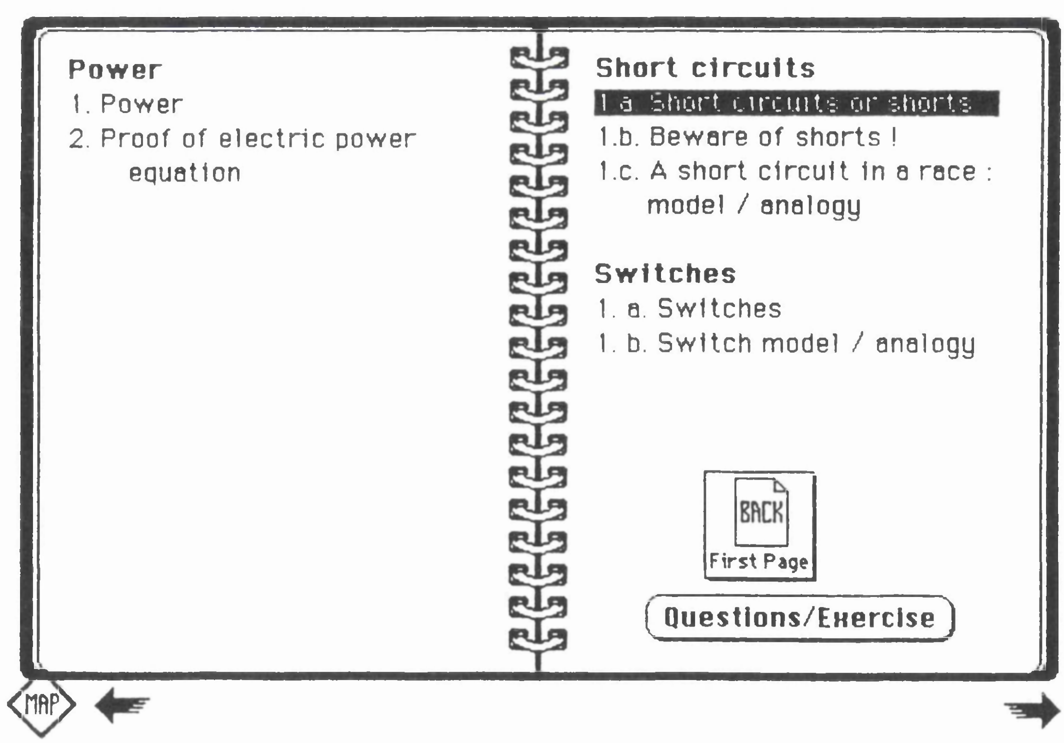


Figure 2-4
a) Shorts
b) Book metaphor

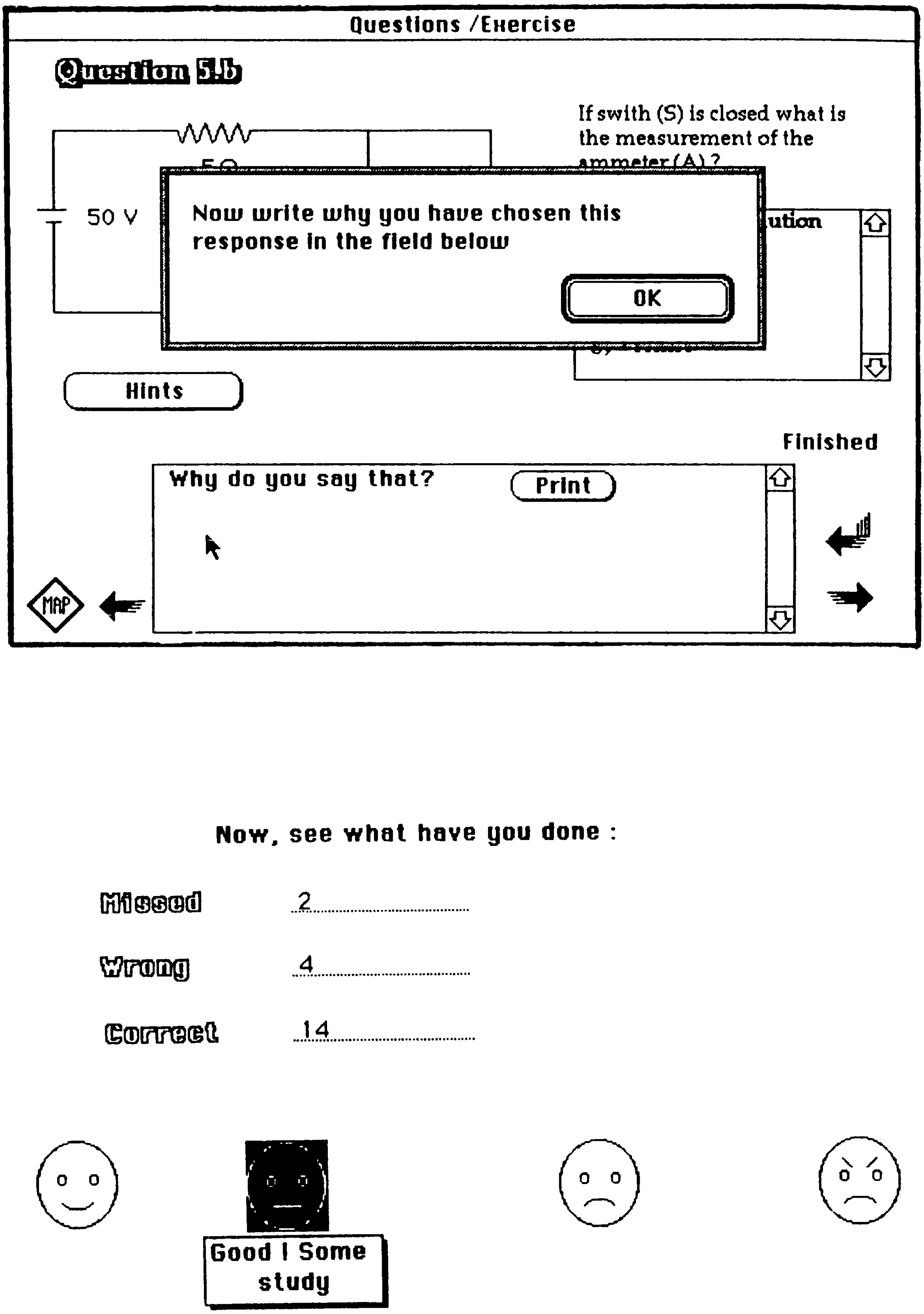


Figure 2-5
a) Typing in text fields
b) Improving results of students' answers

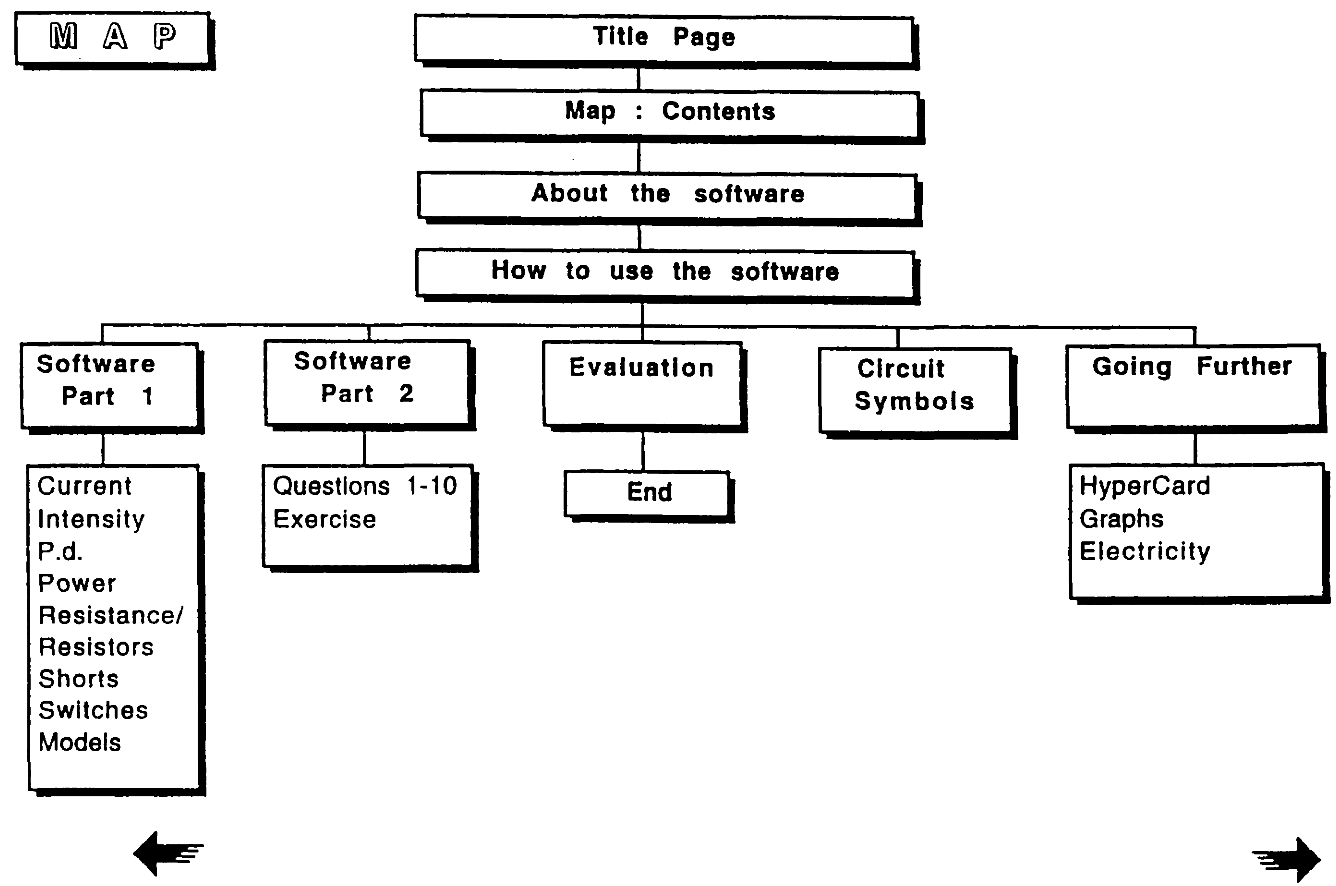
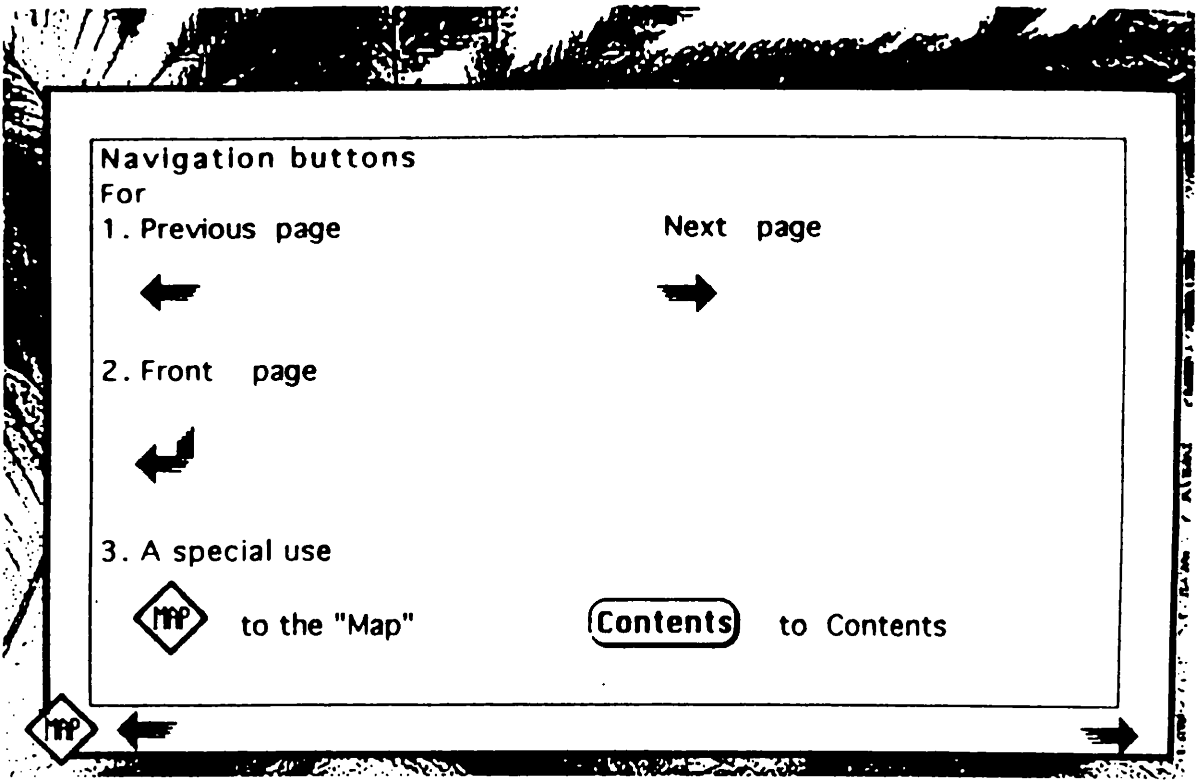


Figure 2-6
Map: An overview of the software



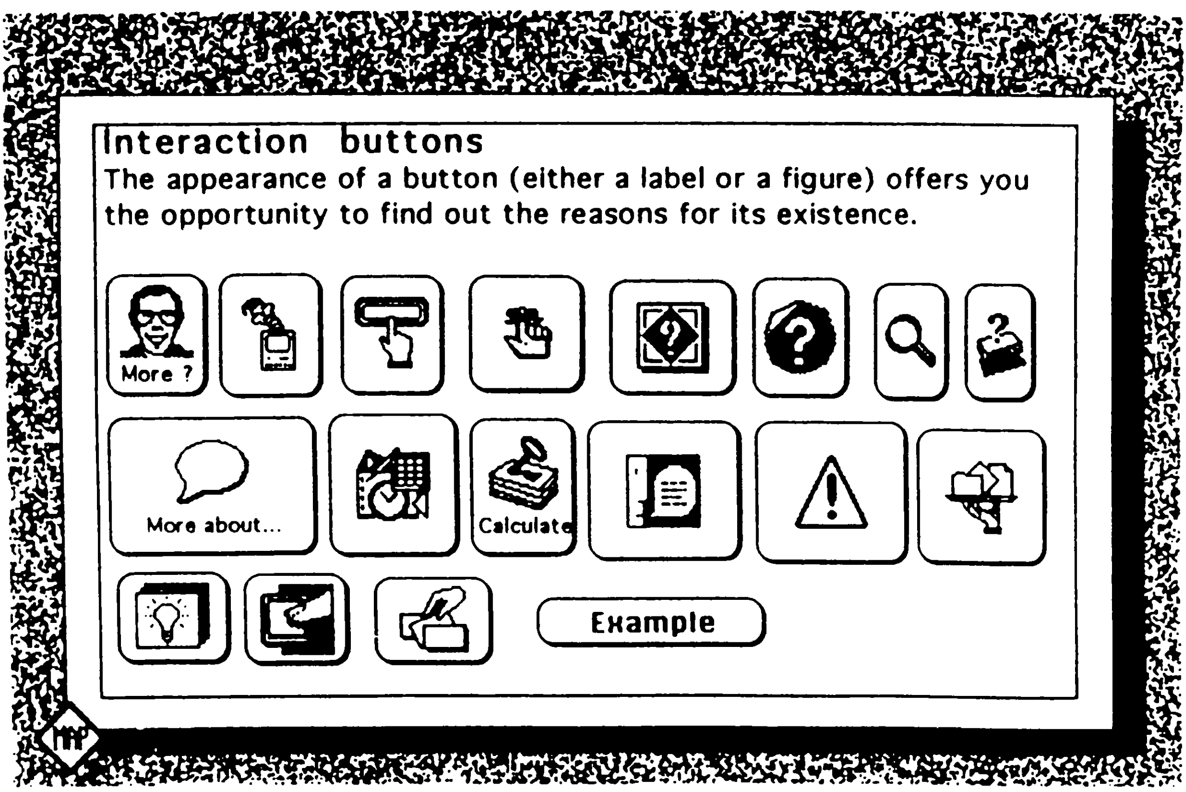


Figure 2-7
a) Buttons for navigation
b) Buttons for interaction

CHAPTER 3

RESULTS
FROM
THE TESTS AND THE QUESTIONNAIRE, ABOUT THE SOFTWARE

This chapter presents:

a) Results from pre, post and delayed-post tests from the students' answers to all of the Questions and their Explanations to the Questions, and answers to the Exercise provided by the software.

b) Results from the questionnaire which was administered after the use of the software.

Both results show generally and quantitatively whether the software can be considered as a learning and teaching tool for some of the topics on Electricity.

c) Results from pre, post and delayed-post tests from the students' answers to the Questions 1 & 6 and their Explanations to these Questions. These should provide evidence, not only quantitatively but also qualitatively, as to whether the software could assist the students' learning of the concept of electric current by overcoming their own misconceptions or alternative frameworks due to its design principles as mentioned in Chapter 2.

3.1 RESULTS FROM PRE, POST AND DELAYED-POST TESTS WITH REFERENCE TO THE SOFTWARE

As previously mentioned, the sample consisted of thirty students with different levels of knowledge of Physics (Electricity). They answered ten multiple choice questions and they gave their own explanations on each one of them. They also did one exercise.

Tables of results from the Analyses of Variance tests (ANOVA test) giving means and level of significance for Questions (QTotPre, QTotPost, QTotDel), Explanations (ExpTotPre, ExpTotPost, ExpTotDel), and Exercises (ExerPre, ExerPost and ExerDel) are provided in the Appendix I (p. 313). Scheffe F-tests were applied between means to identify any significant effects of particular components.

The scores for the questions and explanations were:
correct answer or explanation C or CR = 3
correct but incomplete answer or explanation C? or CR? = 2
wrong answer or explanation W or WR = 1
no answer or explanation No or NoR = 0

The minimum score is 0 and the maximum score (all correct) is 60.

For Questions (Table A-1p. 314, Table A-2 p. 315):
QTotPre = the sum of the scores of the ten questions for every student in the Pre-test,
QTotPost = the sum of the scores of the ten questions for every student in the Post-test,
QTotDel = the sum of the scores of the ten questions for every student in the Delayed Post-test.
From the Tables, there is a significant difference between QTotPre and QTotPost, QTotPre and QTotDel (df=2, 58 F=105.705 p=0.0001). However, there is no significant difference between QTotPost and QTotDel. Thus, there is an increase of the means of scores from the QTotPre (42.1) to QTotPost (57.267) and QTotPre to QTotDel (56.5) (See also Scheffe F-test). Also there is no significant difference in the means of scores between QTotPost and QTotDel.

For Explanations (Table A-3, p. 316, Table A-4 p. 317):
ExpTotPre=the sum of the means of scores for the explanations of the ten questions for the Pre-test,
ExpTotPost=the sum of the means of scores for the explanations of the ten questions for the Post-test,
ExpTotDel=the sum of the means of scores for the explanations of the ten questions for the Delayed Post-test.
From the Tables, there is a significant difference between ExpTotPre and ExpTotPost, ExpTotPre and ExpTotDel (df=2, 58 F=110.702 p=0.0001). Thus, there is an increase of the means of scores between ExpTotPre (36.333) to ExpTotPost (54.033), ExpTotPre (36.333) to ExpTotDel (49.867). There is also a small but significant decrease of the means of scores between ExpTotPost (54.033) to ExpTotDel (49.867).

"Exercise" assessed the students' use of a spreadsheet database and graphics capability (Table A-5 p. 318, Table A-6 p. 319). The scores for the exercise, were:

a) Students who did nothing were marked with zero.

b) Students were given one mark if they had found the Voutput in the voltage divider of the network and given their own values to one of the variables.

c) Students were given two marks if they had found the Voutput in the voltage divider of the network and had given their own values to one of the variables and they had also done the simple line graphs.

d) Students were given three marks if they had found the Voutput in the voltage divider of the network, had given their own values to one of the variables, had produced the simple line graphs, had given some values to the variable R2=not constant, without classifying categories such as R2 increased or R2 decreased; had commented on both graphs Vab=f(V) and i=f(Vab) when R1=R2=constant -consolidation of their knowledge on Ohm's law and the relationship among the quantities i, V and R- and had just mentioned for the third graph that it would be not linear without having drawn it.

e) Students were given four marks if they had found the Voutput in the voltage divider of the network, had given their own values to one of the variables; had given some values to the variable R2=not constant, without classifying categories such as R2 increases and R2 decreases; had commented on both graphs Vab=f(V) and i=f(Vab) when R1=R2=constant -consolidation of their knowledge on Ohm's law and the relationship among the quantities i, V and R; had calculated Voutput for both of the cases R2 increases and R2 decreases and had done an advanced calculations and constructed both linear and polynomial graphs. For example, in a linear graph, y=ax+b, the factors a and b not only were mentioned but also were determined, which shows an advanced ability of drawing graphs.

excellent	**4**	calculations + simple line graphs + comments on graphs + advanced calculations and graph drawing = steps 1+2+3+4
good	**3**	calculations + simple line graphs + comments on graphs = steps 1+2+3
fair	**2**	calculations + simple line graphs = steps 1+2
poor	**1**	calculations = step 1
no	**0**	nothing done = step 0

In the case of the Exercise, there was a significant difference between ExerPre and ExerPost, ExerPre and ExerDel, ExerPost and ExerDel (df=2, 58 F=115.233 p=0.0001). Thus, there is an increase of the means of the scores from ExerPre (1.233) to ExerPost (2.967) and from ExerPre to ExerDel (2.6) (See also Scheffe F-test). There is also a small but significant decrease of the means of scores between ExerPost (2.967) and ExerDel (2.6).

The above mentioned data was also tested by using the Wilcoxon test, for verification and confirmation of the results of the research. Tables of these results are provided in the Appendix I. There is no difference between the results of both tests.

Overall students benefited from using the software, some more than others. The students' level of knowledge of physics became more homogeneous from Pre to Delayed-post test.

Questions and Explanations

a) <u>The number of the students' correct answers to the Questions and of their correct Explanations</u>

With regards to the Questions and Explanations in the Post and Delayed-post tests the mean number of the students' correct answers to the Questions and the mean number of their correct Explanations were greater than those in Pre-test (increase 65% and 84% respectively).

For the Questions in the Pre-test the mean number of the students who answered correctly was 16.3 out of 30 (54%) while in the Post and Delayed-post tests it was 27 out of 30 (90%).

For the Explanations the mean number of the students who gave correct Explanations was 13 out of 30 (43%) in the Pre-test while it became 24 out of 30 (80%) in the Post and Delayed-post tests (Table 4-1).

b) <u>Mean scores of the students' correct answers to the Questions and of their correct Explanations</u>

Furthermore, in the Post and Delayed-post tests the mean scores of the students' correct answers to the Questions and the mean scores of their correct Explanations were also higher than those in Pre-test.

In the case of Questions the (mean) increase of the mean scores of the students' correct answers to the Questions was 15 or 40%.

1) Students with a Low background level in physics
had an increase on the mean scores 76%,

2) Students with a Middle background level in physics
had an increase on the mean scores 31%,
3) Students with a High background level in physics
had an increase on the mean scores 14%.

In the case of Explanations the (mean) increase of the mean scores of the students' correct Explanations was 16 or 52% .

1) Students with a Low background level in physics
had an increase on their mean scores 99%,
2) Students with a Middle background level in physics
had an increase on their mean scores 35%,
3) Students with a High background level in physics
had an increase on their mean scores 22%.

c) Students' population homogeneity

As a result of using the software, the students' population became more homogeneous from Pre to Delayed-post test.

For Questions

Differences in the mean scores for the answers to the Questions between Low & Middle, Middle & High, Low & High background level students were greater in the Pre test than in the Post and Delayed-post tests (Fig. 4-2).

In the Pre-test, the differences of the mean scores for the answers to the Questions between the different levels of students' background in physics were for:

Low & Middle level students 44%,
Middle & High level students 18%,
Low & High level students 69%

while in the Post and Delayed-post tests the differences were for:

Low & Middle level students 7%,
Middle & High level students 3%,
Low & High level students 10%.

For Explanations

Differences in the mean scores for the Explanations between Low & Middle, Middle & High, Low & High background level students were greater in the Pre-test than in the Post and Delayed-post tests (fig. 4-2).

In the Pre-test the differences in the mean scores of the Explanations between the different levels of students' background in physics were for:

Low & Middle level students 81%,
Middle & High level students 17%,
Low & High level students 112%

while in the Post and Delayed-post tests the differences were for:

Low & Middle level students 23%,

Middle & High level students 6%,

Low & High level students 30%.

Exercise

a) Students' performance

With reference to the Exercise in using the spreadsheet the students' performance (the Exercise's mean scores) increased (Table 4-1).

40% of the students did not do anything in the Pre-test while 2% of them did not do anything in the Post and Delayed-post tests.

None of the students (0%) could do advanced calculations and graph drawing in the Pre-test while 28% of them did so.

77% of the students did nothing up to calculations and simple line graphs in the Pre-test (steps 0+1+2) while 95% did calculations and simple line graphs up to advanced calculations and graph drawing in the Post and Delayed-post tests (steps 2+3+4).

b) Students' population homogeneity

As a result of using the software the students' population became more homogeneous from pre to delayed-post test.

With regards to the use of the spreadsheet in the Pre-test their performance ranged from step 0 to step 3, while in the Post and Delayed-post tests their performance ranged from step 2 to step 4 (Table 4-1).

Furthermore with regards to the Exercise's scores, the differences between the mean score of all students' background levels and the mean scores of each level of students' background in physics were greater in the Pre-test (e. g. for Middle level students the difference was 37%) than in the Post and Delayed-post tests (e. g. for Middle level students the difference was 10%).

In addition to the above and with reference to their background in physics, students from Low and Middle levels benefited more (mean scores increase 2) than students from a High level (mean scores increase 1).

3.2 RESULTS FROM THE QUESTIONNAIRE

83% of the students reported that the software environment was user-friendly with simple operation techniques which did not require any special knowledge of computers or any particular skills.

80% of the students claimed that the software provided a logical sequence of data. It also provided activities which encouraged them:

a) to locate and correct mistakes (83%)

b) to find alternative solution to questions (83%)

c) to examine their thinking (83%)

d) to explore information (87%)

e) to break down problems into sub-problems (60%)

Because of the clear illustrations and animated pictures:

a) the software was enjoyable (97%), stimulated their interest (73%) and increased their knowledge about electricity (83%)

b) students gained another way of reasoning (63%), understood better and could explain electrical concepts (57%), consolidated their knowledge (43%).

They also mentioned that they gained:

a) computing skills on HyperCard (40%) and

b) skills in drawing graphs through the provided spreadsheet (47%)

They found their talk with the researcher useful to draw inferences on various topics from the subject domain (37%).

Nearly all students (97% or 29 out of 30), who compared the software to the teaching, stated that the way that the information was presented was remarkable and hence it stimulated (motivated) their interest in the concepts of electricity.

63% of them claimed that the software provided them with the opportunity of collaborative learning

67% of the students would like to spend more time using the software to study and understand more of the theory.

3. 3 RESULTS FROM THE STUDENTS' ANSWERS TO QUESTIONS 1 & 6 AND THEIR EXPLANATIONS

Tables of results of the Analyses of Variance tests (ANOVA test) giving means and level of significance for each Question and Explanation are provided in the Appendix I (p. 320-323). Scheffe F-tests were applied between means to identify any significant effects of particular components.

The above data was also tested by using the Wilcoxon test. The tables of results are provided in the Appendix I. There is no difference between the results from both tests.

Question 1 & Explanation 1

<u>Question 1.a</u>

From the Tables, there is no significant difference between Q1.a Pre and Q1.a Post, Q1.a Pre and Q1.a Del, Q1.a Post and Q1.a Del (df=2, 58 F=1 p=0.3741). Thus, the mean scores of Q1.a did not increase from Pre test (2.933) to Post test (3) and Delayed-post test (3). Only one student out of 30 gave a wrong answer on the Pre test. All students answered correctly in the Post and Delayed-post tests.

<u>Explanation 1.a</u>

From the Tables, there is a small, but significant increase between E1.a Pre and E1.a Post, E1.a Pre and E1.a Del. There is no significant difference between E1.a Post and E1.a Del (df=2, 58 F=6.566 p=0.0027). The mean scores have a small but significant increase from Pre-test (2.6) to Post test (3) and Delayed-post test.

<u>Question 1.b</u>

From the Tables, there is a significant difference between Q1.b Pre and Q1.b Post, Q1.b Post and Q1.b Del. However, there is no significant difference between Q1.b Post and Q1.b Del (df=2, 58 F=22.176 p=0.0001). Thus, the mean scores of Q1.b increase from Pre test (2.133) to Post test (3) and Delayed-post test (3).

<u>Explanation 1.b</u>

From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 1.b than for Question 1.b. There is no significant difference between E1.b Post and E1.b Del (df=2, 58 F=26.141 p=0.0001). The mean scores have a significant increase from Pre test (1.933) to Post test (3) and Delayed-post test (3).

<u>Question 1.c</u>

From the Tables, there is no significant difference between Q1.c Pre and Q1.c Post, Q1.c Pre and Q1.c Del, Q1.c Post and Q1.c Del (df=2, 58 F=1 p=0.3741). Thus, the mean scores of Q1.c have not any increase from Pre test (2.933) to Post test (3) and Delayed-post test (3). Only one student out of 30 gave a wrong answer on the Pre test. All students answered correctly in Post and Delayed-post tests.

<u>Explanation 1.c</u>

From the Tables, there is a small, but significant increase between E1.c Pre and E1.c Post, E1.c Pre and E1.c Del. There is not significant difference between E1.c Post and E1.c Del (df=2, 58 F=8.898 p=0.0004). The mean scores have a small but significant increase from Pre test (2.4) to Post test (3) and Delayed-post test (3).

Question 1.d

From the Tables, there is a significant difference between Q1.d Pre and Q1.d Post, Q1.d Post and Q1.d Del. However, there is no significant difference between Q1.d Post and Q1.d Del (df=2, 58 F=19.333 p=0.0001). Thus, the mean scores of Q1.d have an increase from Pre test (2.2) to Post test (3) and Delayed-post test (3).

Explanation 1.d

From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 1.d than for Question 1.d. There is no significant difference between E1.d Post and E1.d Del (df=2, 58 F=23.25 p=0.0001). The mean scores have a significant increase from Pre test (2.033) to Post test (3) and Delayed-post test (3).

Question 1

All students gave correct answers to the Questions 1.a, 1.b, 1.c, 1.d in the post and delayed-post tests while nearly all students (29 out of 30 or 97%) for the Questions 1.a and 1.c. in the Pre-test.

The number of the students' correct answers to the Questions 1.b and 1.d had a significant increase of 76% and 67% from the pre to the post and delayed-post tests.

The mean scores of the Questions 1.b and 1.d had also a significant increase of 36% and 32% while the increase was 2% for the rest of the questions.

The students' population ability to answer Question 1 became homogeneous regardless of their prior background in physics.

Additionally, Low and Middle level students benefited.

All students of the Low level benefited in both questions 1.b and 1.d.

In the case of the Middle level students:

3 out of 10 (30%) of them improved their answers to the question 1.b and

2 out of 10 (20%) of them to the question 1.d.

Thus, on average, 25% of the Middle level students improved their answers to Questions 1.b and 1.d.

Explanation 1

All students gave correct explanations to Question 1 in the post and delayed-post tests.

From pre to post and delayed-post tests the number of the students' correct explanations to Question 1 had a significant increase which ranged from 30%

(Explanation 1.a) to 100% (Explanation 1.b). The mean scores of their Explanations had also a significant increase which ranged from 15% (Explanation 1.a) to 50% (Explanation 1.b).

As in Question 1, the students' population ability to explain Question 1 became homogeneous regardless of their prior background in physics.
Additionally, Low and Middle level students benefited.
All students of the Low level benefited in both Explanations 1.b and 1.d.
In the case of the Middle level students

5 out of 10 (50%) of them improved their Explanations to the question 1.b and

3 out of 10 (30%) of them to the question 1.d.

Thus, on average, 40% of the Middle level students improved their Explanations 1.b and 1.d.

Question 6 & Explanation 6

<u>Question 6.a</u>
From the Tables, there is a significant difference between Q6.a Pre and Q6.a Post, Q6.a Post and Q6.a Del. However, there is no significant difference between Q6.a Post and Q6.a Del (df=2, 58 F=8.529 p=0.0006). Thus, the mean scores of Q6.a have an increase from Pre test (2.5) to Post test (3) and Delayed-post test (3).
<u>Explanation 6.a</u>
From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 6.a than for Question 6.a. There is no significant difference between E6.a Post and E6.a Del (df=2, 58 F=20.767 p=0.0001). The mean scores have a significant increase from Pre test (2.133) to Post test (3) and Delayed-post test (3).
<u>Question 6.b</u>
From the Tables, there is a significant difference between Q6.b Pre and Q6.b Post, Q6.b Post and Q6.b Del. However, there is no significant difference between Q6.b Post and Q6.b Del (df=2, 58 F=18.782 p=0.0001). Thus, the mean scores of Q6.b have an increase from Pre test (2.167) to Post test (3) and Delayed-post test (3).
<u>Explanation 6.b</u>
From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 6.b than for Question 6.b. There is no significant difference between E6.b Post and E6.b Del (df=2, 58 F=20.767 p=0.0001). The mean scores have a significant increase from Pre test (2.133) to Post test (3) and Delayed-post test (3).

Question 6.c

From the Tables, there is a significant difference between Q6.c Pre and Q6.c Post, Q6.c Post and Q6.c Del. However, there is no significant difference between Q6.c Post and Q6.c Del (df=2, 58 F=18.782 p=0.0001). Thus, the mean scores of Q6.c have an increase from Pre test (2.167) to Post test (3) and Delayed-post test (3).

Explanation 6.c

From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 6.c than for Question 6.c. There is no significant difference between E6.c Post and E6.c Del (df=2, 58 F=20.767 p=0.0001). The mean scores have a significant increase from Pre test (2.133) to Post test (3) and Delayed-post test (3).

Question 6.d

From the Tables, there is a significant difference between Q6.d Pre and Q6.d Post, Q6.d Post and Q6.d Del. However, there is no significant difference between Q6.d Post and Q6.d Del (df=2, 58 F=18.782 p=0.0001). Thus, the mean scores of Q6.d have an increase from Pre test (2.167) to Post test (3) and Delayed-post test (3).

Explanation 6.d

From the Tables, there is a greater significant increase between Pre and Post, Pre and Delayed-post test for Explanation 6.d than for Question 6.d. There is no significant difference between E6.d Post and E6.d Del (df=2, 58 F=20.767 p=0.0001). The mean scores have a significant increase from Pre test (2.133) to Post test (3) and Delayed-post test (3).

Question 6

As in Question 1, all students gave correct answers to Question 6 in the post and delayed-post tests.

In the pre-test the majority of the students (80%) only gave correct answers to Question 6.a while a considerable number of them (60%) gave correct answers to each of the Questions 6.b, 6.c, 6.d.

From the pre-test to the post and delayed-post tests the mean scores of the question 6 had also a significant increase which ranged from 17% (Question 6.a) to 41% (each of Questions 6.c and 6.d).

As a result, the students' population became completely homogeneous in the post and delayed-post tests with respect to the background level of physics.

Additionally, Low and Middle level students benefited.

All students of the Low level benefited in the questions 6.b, 6.c, 6.d while 5 out of 10 (50%) of them benefited in Question 6.a.

In the case of the Middle level students

2 out of 10 (20%) of them improved their answers to the Questions 6.b, 6.c, 6.d and

3 out of 10 (30%) of them to the question 6.a.

Thus, on average, 25% of the Middle level students benefited to the all of the Questions 6 by the software.

Explanation 6

All students gave correct Explanations to Question 6 in the Post and Delayed-post tests.
In the Pre-test nearly the same number of students gave correct Explanations to each of the Questions. For Explanations 6.a, 6.b, 6.c it was 17 out of 30 students (57%) and for Explanation 6.d it was 18 out of 30 students (60%).
From the Pre-test to Post and Delayed-post tests the number had a significant increase of 76% for Explanations 6.a, 6.b, 6.c and 67% for Explanation 6.d. The mean scores had also a significant increase which was 36% (Expl. 6.a) and 41% (Expl. 6.b, 6.c, 6.d).

With respect to the background level of physics, the students' population became completely homogeneous in the post and delayed-post tests.
In addition to this, Low and Middle level students benefited.
All students from the Low level benefited, while in the case of the Middle level students 3 out of 10 (30%) of them improved their Explanations to Questions 6.a, 6.b, 6.c and 6.d.

CHAPTER 4

DISCUSSION OF RESULTS FROM THE SOFTWARE, THE QUESTIONNAIRE, THE QUESTIONS 1 & 6 AND THEIR EXPLANATIONS

This chapter includes a detailed analysis of:

a) Results from pre, post and delayed-post tests from the total scores of students' answers to the Questions and their Explanations to the Questions, and to the Exercise provided by the software.

b) Results from the questionnaire which was administered after the use of the software.

c) Results from pre, post and delayed-post tests from the students' answers to the Questions 1 & 6 and their Explanations to these Questions.

In Part (I) of the chapter, the results are analysed quantitatively.
A detail discussion follows and examines whether:

a) Students benefited from the use of the software

b) An improvement of their performance was observed

Additionally, a qualitative analysis of students' comments from the Questionnaire follows, in which learning is related to their attitudes to the software.

In the Part (II) of this chapter, the results are analysed qualitatively.
The discussion focuses on:

a) Problems on understanding the concepts of current, potential difference and resistors and their relationship in a circuit.

b) Both strategies to avoid misconceptions and strategies for conceptual change in the software design within the framework of useful models of the electrical concepts.

Finally, the discussion analyses whether the software is a learning & teaching tool which can assist the students' understanding of the concept of electric current by overcoming their relevant misconceptions according to its design principles, as mentioned in Chapter 2.

PART (I)

4.1 DISCUSSION ON THE RESULTS FROM PRE, POST AND DELAYED - POST TESTS WITH REFERENCE TO THE SOFTWARE

4.1.1 QUESTIONS

a) Mean number of students' correct answers to Questions

From Table 4-1, the mean number of students who gave correct answers to Questions had a significant increase of 65% (26.85-16.3)/16.3 from pre to post and delayed-post test.

In the pre-test the mean number of students was 16.3 out of 30 (54%). Their correct answers ranged from 3% (1 out of 30 in question 9) to 100% (all students in question 5.a).

In the post and delayed-post test the mean number of students was 26.85 out of 30 (90%). Their correct answers ranged from 35% (10.5 out of 30 in question 8) to 100% (all students questions 1, 3.a, 5.a, 5.b, 6).

b) Comments on graphs

b1) Mean scores of students' answers to Questions

From fig. 4-1, fig. 4-2, fig. 4-3 and fig. 4-4, all students also presented a great and statistically significant increase in the mean scores in questions from pre to post test [fig. 4-1 and fig. 4-2 Que(PrePostDel)=f(level)].

	Pre	Post	Difference	
Low	30.6	54.6	24	greatest
Middle	43.9	57.9	14	less
High	51.8	59.3	7.5	least

and a small, but not statistically significant decrease from post to delayed-post test

	Post	Delayed-post	Difference	
Low	54.6	53.2	1.4	greatest
Middle	57.9	57.4	0.5	less
High	59.3	58.9	0.4	least

If we consider the mean of scores of post and delayed-post tests then

	Mean (Post+Del)	
Low	53.8	~ 54
Middle	57.65	~ 58
High	59.1	~ 59

Comparing the scores

	Pre	Post+Del	Difference		Mean Dif/ce
Low	31	54	23	greatest	
Middle	44	58	14	less	15
High	52	59	7	least	

	Difference (%)	Mean Dif/ce (%)
Low	76%	
Middle	31%	40%
High	14%	

The above results showed that :

1) Overall, students gained benefit from the software. The mean increase of the mean scores of students' correct answers to Questions was 15 or 40%. Some of them benefited more (Low level 76%) and some less (High level 14%).

2) The differences of mean scores between the post and delayed-post tests for each of the levels of their background knowledge in physics have reduced remarkably.

a) Students' mean scores ranged from 54 to 59 while the scores ranged from 31 to 52 in pre-test.

b) With reference to the students' physics knowledge the lack of homogeneity in the students' population from low to high level also became significantly less, which is considered as an indicator of a good learning environment.

b2) <u>Differences in the mean scores of students' answers to Questions between their levels of background knowledge</u>

From fig. 4-3 and fig. 4-4, the differences in the mean scores of students answers to Questions between the levels of background knowledge were:

	Pre	Post+Del	Pre(%)	Post+Del(%)
Low&Middle level	13.3	3.75	44%	7%
Middle&High level	7.9	1.45	18%	3%
Low&High level	21.2	5.2	69%	10%

The above results showed that :

1) The differences in the mean scores of students' answers to Questions between the levels of students' background knowledge in physics have also reduced remarkably from pre to post and delayed-post tests.

2) The differences ranged from 3% (Middle&High) to 10% (Low&High) in Post and Delayed-Post test and from 18% (Middle&High) to 69% (Low&High) in the Pre-test.

The smaller the differences the greater the homogeneity. As in the above mentioned results the student population became more homogeneous as far as their background knowledge in physics is concerned.

b3) <u>Comparing the slopes of the Line Chart graphs</u>

Furthermore, comparing the slopes and the height differences of line graphs QuePre, QuePost and QueDel=f(level) (fig. 4-2) between the points Low and Middle (level), the slope of the line QuePre = f(level) is greater than both QuePost and QueDel = f(level). There are great differences at both starting and ending points

Difference between starting points (Low on x-axis)

QuePost - QuePre = 54.6 - 30.6 = 24 QueDel - QuePre = 53.2 - 30.6 = 22.6

Difference between ending points (Middle on x-axis)

QuePost - QuePre = 57.9 - 43.9 = 14 QueDel - QuePre = 57.4 - 43.9= 13.5

Both QuePost and QueDel = f(level) between the points Low and Middle (level) also have about the same slope [the slope of QueDel = f(level) is a little bit less than QuePost = f(level)], and their starting and ending points are in the same region.

Difference between starting points (Low on x-axis)

QuePost - QueDel = 54.6 - 53.2 = 1.4

Difference between ending points (Middle on x-axis)

QuePost - QueDel = 57.9 - 57.4 = 0.5

Comparing the slopes of line graphs QuePre, QuePost and QueDel =f(level) between the points Middle and High (level), the slope of the line QuePre = f(level) is greater than both QuePost and QueDel = f(level). There are great differences -but less than in the previous case between Low and Middle (level)- at both starting and ending points.

Difference between starting points (Middle on x-axis)

QuePost - QuePre = 57.9 - 43.9 = 14 QueDel - QuePre = 57.4 - 43.9= 13.5

Difference between ending points (High on x-axis)

QuePost - QuePre = 59.3 - 51.8 = 7.5 QueDel - QuePre = 58.9 - 51.8 = 7.1

Both QuePost and QueDel = f(level) also have similar slope and their difference on starting and ending points are in the same region.

Difference between starting points (Middle on x-axis)

QuePost - QueDel = 58 - 57.5 = 0.5

Difference between ending points (High on x-axis)
QuePost - QueDel = 59.4 - 59 = 0.4

Consequently, comparing:
1) The slopes of the line graphs QuePre, QuePost and QueDel = f(level) (fig. 4-2) between the points Low&Middle, Middle&High, the line graphs QuePost and QueDel = f(level) are approximately the same [both QuePost and QueDel=f(level) are higher than the line graph QuePre = f(level) and quite similar and at the same height].
2) The slopes of both line graphs QuePost and QueDel = f(level) between the points Low&Middle, Middle&High are smaller than the slopes of the line graph QuePre = f(level) between the same points. The smaller the slopes the greater the students' population homogeneity of background knowledge in physics.

Not only the line graph Que(PrePostDel)=f(level) (fig. 4-2) but also Que(HML)=f(test) (fig. 4-4) showed all students benefited by using the software in that they answered the questions correctly.

With particular reference to the students' background knowledge in physics:
1) The greatest benefit (increase on the mean scores of students' correct answers to Question) was obtained by low level students because they correctly answered more questions in the post and delayed-post tests (76%) than in the pre-test; there was less benefit by middle level students (31%) and the least benefit of all by high level students (14%).
2) Comparing both line graphs, the greatest difference in the mean scores of students' correct answers occurred with low level students (decrease 1.4 or 3%) because they correctly answered fewer questions in the delayed-post tests than in the post-test; less difference occurred with middle level students (decrease 0.5 or 0.008%) and the least difference occurred with high level students (decrease 0.4 or 0.006%).
3) Comparing the slopes of both line graphs the student population became more homogeneous as the slopes decreased more.

c) Concluding remarks on Questions

1) Overall students correctly answered the Questions in both Post and Delayed-post tests.
2) Students of low background level physics gained more benefit from the software than the students of the other two levels - proof being that their scores increased the most.

3) Overall, for all students' levels great differences existed between pre and post, pre and delayed-post tests scores but there was no significant difference between post and delayed-post tests. As a result, the students' homogeneity increased from Pre to Post and Delayed-post tests.

4. 1. 2 EXPLANATIONS

a) Mean number of students' correct Explanations

From Table 4-1, the mean number of students who gave correct Explanations to Questions had a significant increase 84% (23.85-13)/13 from pre to post and delayed-post tests.

In the pre-test the mean number of students was 13 out of 30 (43%). Their correct explanations ranged from 0% (in question 10) or 3% (1 out of 30 in questions 3.c, 8, 9) to 100% (all students in question 5.a).

In the post and delayed-post tests, the mean number of students was 23.85 out of 30 (80%). Their correct explanations ranged from 17% (5 out of 30 in question 10) to 100% (all students questions 1, 6). Additionally the number of their correct explanations was 19.5 out of 30 (65%) in question 3.c, 6.5 out of 30 (22%) in question 8, 8.5 out of 30 (28%) in question 9.

b) Comments on the graphs

b1) Mean scores of students' Explanations

As with the Questions, from Pre to Post test all students presented an increase in mean scores of their Explanations while answering the questions , as shown in fig. 4-5, fig. 4-6, fig. 4-7 and fig. 4-8.

	Pre	Post	Difference	
Low	22.2	48	25.8	greatest
Middle	39.9	55.7	15.8	less
High	47.1	58.4	11.3	least

From Post to Delayed-post test, as with the Questions, all students presented a small, but significant decrease in the mean scores of their Explanations.

	Post	Delayed-post	Difference	
Low	48	40.2	7.8	greatest
Middle	55.7	52.8	2.9	less
High	58.4	56.6	1.8	least

The mean of the scores between post and delayed-post test

	Mean (Post+Del)	
Low	44.1	~ 44

Middle	54.25	~ 54
High	57.5	~ 58

Comparing the scores

	Pre	Post+Del	Difference		Mean Dif/ce
Low	22	44	22	greatest	
Middle	40	54	14	less	16
High	47	58	11	least	

	Difference (%)	Mean Dif/ce (%)
Low	99%	
Middle	35%	52%
High	22%	

The above results showed that:

1) All students benefited from the software. The (mean) increase of the mean scores of students' Explanations was 16 or 52%. Some of them benefited more (Low level 99%) and some of the others less (High level 22%).

2) The differences in the mean scores of students' Explanations between the post and delayed-post tests for each of the levels of the background knowledge in physics have also reduced.

a) Students' means scores on Explanations ranged from 44 to 58 in post and delayed-post tests while from 22 to 47 in pre-test.

b) As a result, the students' homogeneity increased, which is an indicator for a good learning environment.

c) In the case of Explanations these differences in the mean scores between the post and delayed-post tests for each of the levels of the background knowledge in physics were greater than the appropriate differences in the case of Questions.

This can be interpreted by the fact that explaining an answer to a question requires correct expressions by using relevant and accurate terminology. Similar findings were reported by Gott (1985, p.p. 63-72). According to Heller (1987) and Webb (1992), even Elementary School teachers and Middle School Science teachers gave incomplete or incorrect explanations.

In addition, Shipstone (1984) stressed that the sequential reasoning model was used not only by pupils of age range between 12 - 17 years old, but also by 7 out of 18 physics and engineering graduates training to be physics teachers. Their incomplete or incorrect explanations were considered as a result of its persistence.

Furthermore, a mathematical procedure - which was not so familiar to the students - was required to explain a question. For instance in Question 10, the

students claimed that in some of the other questions that they could not remember how to go on from the first formula and to arrive at the second and/or the third and/or the fourth one, although they knew all the formulae. In other cases, they preferred only verbal expressions, avoiding formulae. As a result of this the students' scores were reduced.
We also need to take into account the long period between lectures in October and the delayed-post test in March of the same academic year. During this period there were no lectures, laboratory or other work relevant to the subject domain.

b2) Differences in the mean scores of students' Explanations between their levels of knowledge background in physics

From fig. 4-6, the differences in the mean scores of students' Explanations between the levels of background knowledge in physics were for:

Levels	Pre	Post+Del	Pre(%)	Post+Del(%)
Low&Middle	17.7	10.15	80% (17.7/22.2)	23% (10.15/44.1)
Middle&High	7.2	3.25	18% (7.2/39.9)	6% (3.25/54.25)
Low&High	24.9	13.4	112% (24.9/22.2)	30% (13.4/57.5)

The above results showed that:
1) As mentioned previously in the Questions, the differences in the mean scores of Explanations between the levels of students' background knowledge in physics were remarkably reduced from pre to post and delayed-post tests.
2) The differences ranged from 6% (Middle&High) to 30% (Low&High) while from 18% (Middle&High) to 112% (Low&High) in the Pre-test.
3) The smaller the differences the greater the students' homogeneity. Similarly, not only to the above mentioned but also to previously mentioned remarks on Questions, the student population became more homogeneous with respect to students' background knowledge in physics.
4) As in the above mentioned 2.c, in the case of Explanations these differences in the mean scores between the levels of students' background knowledge in physics were also greater than the appropriate differences in the case of Questions. Thus, this can also be explained as above.

b3) Comparing the slopes of the Line Chart graphs

Furthermore in fig. 4-6, comparing the slopes and the height differences of line graphs ExplPre, ExplPost and ExplDel = f(level) between Low and Middle level were greater than between Middle and High level, as was the case with the Questions. Especially, between Low and Middle level points the slope and the height difference of the line ExplPre = f(level) is greatest, the slope and the height difference of ExplDel = f(level) is less and the slope and the height difference of ExplPost = f(level) is least. Both ExplPost = f(level) and ExplDel = f(level) are closer to each other than to each of them from ExplPre = f(level).

Between the Low and Middle points the slope of ExplPre = f(level) is greater than the two others, ExplPost and ExplDel = f(level). There is a great difference between starting and ending points.
At the starting points there is a difference (Low on x-axis)
ExplPost - ExplPre = 48 - 22.2 = 25.8   ExplDel - ExplPre = 40.2 - 22.2 = 18
At the ending points there is also a smaller difference (Middle on x-axis)
ExplPost - ExplPre = 55.7 - 39.9 = 15.8   ExplDel - ExplPre = 52.8 - 39.9 = 12.9

Between the Low and Middle points both ExplPost and ExplDel = f(level) have a small but statistically significant difference in slopes. There is a difference between the starting and ending points.
At their starting points there is a difference (Low on x-axis)
ExplPost - ExplDel = 48 - 40.2 = 7.8
At the ending points there is a smaller difference (Middle on x-axis)
ExplPost - ExplDel = 55.7 - 52.8 = 2.9

Between the Middle and High points the slope of ExplPre = f(level) is greater than the two others ExplPost and ExplDel = f(level). There is a great difference between the starting and ending points.
At the starting points there is a difference (Middle on x-axis)
ExplPost - ExplPre = 55.7 - 39.9 = 15.8   ExplDel - ExplPre = 52.8 - 39.9 = 12.9
At the ending points there is also a smaller difference (High on x-axis)
ExplPost - ExplPre = 58.4 - 47.1 = 11.3   ExplDel - ExplPre = 56.6 - 47.1 = 9.5

Between the Middle and High points, both ExplPost and ExplDel = f(level) have a small difference in slopes. There is a difference between their starting and ending points but less than in the previous case between Low and Middle (level).
At the starting points there is a difference (Middle on x-axis)
ExplPost - ExplDel = 55.7 - 52.8 = 2.9
At the ending points there is a smaller difference (High on x-axis)
ExplPost - ExplDel = 58.4 - 56.6 = 1.8

The above mentioned graphs showed that:
1) Comparing the slopes of the line graphs ExplPre, ExplPost and ExplDel = f(level) (fig. 4-6) between the points Low & Middle (level), Middle & High (level):

a) The line graph ExplPre = f(level) has a large height difference with each of the ExplPost and ExplDel = f(level).

b) Both ExplPost and ExplDel = f(level) are close to each other but they differ slightly in height difference.

2) The slopes of the line graphs ExplPost and ExplDel = f(level) between the points Low and Middle(level), Middle and High(level) are smaller than the slopes of the line graph ExplPre = f(level) between the same points. As in Questions, the smaller slopes and height differences showed greater homogeneity of the students' population concerning their background knowledge in physics.

Not only the line graph Expl(PrePostDel) = f(level) (fig. 4-6) but also Expl(HML) = f(test) (fig. 4-8) showed that the students' ability to give correct (and complete) explanations while answering the Questions was increased by the use of the software.

Furthermore, similarly to the above mentioned line graphs, the bar graphs in fig. 4-5 and fig. 4-7 also showed that all students benefited from the software, because their scores on explanations increased in the Post and Delayed-post test (mean increase 52%), compared to the Pre test..

Especially with regard to their background knowledge in physics :

1) Students of Low level (99% of them) befitted most, students of Middle level (35% of them) benefited less, and the least benefit was gained by students of High level (22% of them).

2) Comparing ExplPost and ExplDel = f(level), on the points Low and Middle, Middle and High(level) there were differences in the students' Explanations scores. The greatest difference was for students of Low level physics background (decrease 7.8 or 16%), less difference by students of Middle level (decrease 2.9 or 5%) and the least difference by students of High level (decrease 1.8 or 3%).

c) Concluding remarks on Explanations

1) In general, students gave better Explanations to Questions in both post and delayed-post tests.

2) There is also a small, but significant, decrease in the students' Explanations scores between post and delayed-post tests. The reason is that in order for the students to explain an electrical concept the accurate use of terminology is required; while by using the software they could use the theoretical feedback to check their way of thinking and of course their Explanation.

3) With reference to the levels of their physics background:

a) Students from the Low level gained the most benefit from the software, shown by the greatest increase in their Explanations scores, students of Middle level gained less and students of High level gained the least benefit.

b) The student population became more homogeneous from pre to delayed-post test.

c) In general, there was a small and insignificant decrease from the post to the delayed-post test. This decrease became greater in the case of students from a Low background level in physics, less in the case of Middle background level students and least in the case of High background level students.

d) Concluding remarks on the comparison of Questions and Explanations

1) From Pre to Post and Delayed-post test there was an increase in the number of students who gave correct answers and correct Explanations to each of the Questions (Table 4-1).
2) The differences in the number of students' correct answers and their correct Explanations to the Questions reduced from Pre to Post and Delayed-post tests.
3) In post and delayed-post tests both scores for Questions and Explanations were substantially higher than scores in pre-test for all students (Low, Middle and High level) (fig. 4-12).
4) Taking into account that the students' correct Explanations showed real learning - not just ticking an answer - the mentioned increase can be explained by the fact that the software had a positive influence on students' learning.
5) The mean scores of Questions were higher than the mean scores of Explanations in Pre, Post and Delayed-post tests for students of all physics background levels (fig. 4-9 and fig. 4-11).
6) The differences in mean scores between Questions and Explanations were greatest in the Low level students, less in the Middle level students and least in the High level students (fig. 4-10).
7) The differences in mean scores between Questions and Explanations reduced from Pre to Post test. The difference became smaller in the post test. than in the Pre test. Their difference had a small but statistically significant increase from Post to Delayed-post test. One direct result was that students' population became more homogeneous from pre to post and delayed-post tests with respect to their levels of background knowledge in physics.

8) The increase in the mean scores for Questions and Explanations, and between post test and delayed-post test, was the greatest for students with a Low level of background knowledge in physics, less for students with Middle level and the least for students with High level.
As mentioned previously, explaining an answer to any question requires correct expressions and the use of relevant and accurate terminology. In the literature there are references in which even teachers have been known to give these sorts of explanations.
Additionally, there were two negative influences on their learning:

a) The long period of time between lectures on the subject domain in October and the Delayed-post test in March of the academic year - in which no lecture, laboratory and/or other relevant work have been done

b) The fact that no facility has been provided by the software, such as theoretical feedback for reminding the students of the concepts in detail.

4. 1. 3 EXERCISE

a) Students' performance in the Exercise

The students' performance had a significant increase with the use of the provided spreadsheet (Table 4-1).
In Pre-test, 12 out of 30 students (40%) did not do anything while 0.5 out of 30 students (2%) did not do anything in post and delayed-post tests. None of them did advanced calculations and graph drawing (step 4) in Pre-test while 8.5 out of 30 (28%) did step 4 in post and delayed-post tests.

Furthermore, in the pre-test the majority of the students 23 out of 30 (77%) did steps 0+1+2 and the minority 7 out of 30 (23%) did steps 0+1+2+3. However, in post and delayed-post tests nearly all of them 28.5 out of 30 (95%) did steps 2+3+4 while only 3% of them did step 1 and 2% of them did nothing.

Thus, in the Pre-test, the students' performance in the Exercise ranged from doing nothing to fair use of the spreadsheet by the majority of them; while in the Post and Delayed-post tests there was fair to excellent use of the spreadsheet by nearly all of them.

With reference to the levels of the students' performance, in pre-test their performance ranged from step 0 to step 3, while in post and delayed-post test ranged from step 2 to step 4.

This shows that the student population became more homogeneous in the post and delayed-post tests than in the pre-test.

b) Comments on the Exercise's graphs

b1) <u>Students' mean scores in the Exercise</u>
The students showed a high increase in the mean scores for Exercise from the pre-test to post test, and from pre-test to delayed-post test for each level of the students' background knowledge in physics, as shown in fig. 4-13, fig. 4-14, fig. 4-15 and fig. 4-16.

	Pre	Post	Difference	
Low	0.1	2	1.9	greater
Middle	0.9	3	2.1	greater
High	2.7	3.9	1.2	less

There was a small but significant decrease in their scores from post to delayed-post test for each level of background knowledge in physics.

	Post	Delayed-Post	Difference	
Low	2	2	0	no
Middle	3	2.2	0.8	greater
High	3.9	3.6	0.3	less

The mean of the scores between post and delayed-post test

	Mean (Post+Del)	
Low	2	~2
Middle	2.6	~3
High	3.75	~4

Comparing the scores

	Pre	Mean (Post+Del)	Difference	
Low	0	2	2	greatest
Middle	1	3	2	greatest
High	3	4	1	least

The above results showed that:
1) Overall, students gained benefit from the software; some of them more than others.
2) Referring to background of physics and taking into account Table 4-1:

a) Students from a Low background level presented the greatest increase in the scores in Exercise, from pre to post test and no difference from post to delayed-post test.

In the Pre-test, the majority of them 9 out of 10 students (90%) did nothing [except one student (10%) who calculated Voutput of the voltage divider and gave his own values in one of the variables = step 1].
In the post and delayed-post tests nearly all of them 8 out of 10 (80%) calculated Voutput of the voltage divider, gave their own values in one of the variables and they also did the single line graphs i=f(Vab) and Vab=f(V) for R1=R2=constant (steps 1+2). Additionally, the above mentioned student did not improve and another one out of 10 (10%) did steps 1+2+3.
Hence, the students with a Low background level of knowledge in physics performed a fair use of the spreadsheet in the Post and Delayed-post tests.

b) Students from a Middle background level also showed the greatest increase of scores for pre-test 0.9 to post test 3.0. However, they showed a small but significant decrease from post test 3.0 to delayed-post test 2.2.

In the pre-test 50% of them did step 1, while 30% of them did nothing and 20% did steps 1+2.

In the post test 60% of them did steps 1+2+3, while 20% of them did steps 1+2+3+4 and 20% did only steps 1+2.

In the Delayed-post test 50% of them did steps 1+2, while 40% of them did steps 1+2+3 and 10% did nothing.

Thus, in the pre-test the students attempted to do step 1, in the post test step 1, step 2 and step 3 while in the delayed-post step 1 and step 2. This fact was due to the facilities provided by the spreadsheet.

In the Post and Delayed-post tests 50% of them did steps 1+2+3, while 10% of them did steps 1+2+3+4, 30% of them did only steps 1+2, 5% did only step 1 and 5% did nothing.

Taking into account the mean of scores of post and delayed-post tests the students performed successfully steps 1+2, and almost step 3.
Consequently, the students of Middle background level of knowledge in physics made good use of the spreadsheet in the Post and Delayed-post tests.

c) Students from a High background level showed the least (smallest) increase of scores in the Exercise from pre-test 2.7 to post test 3.9 and a smaller but significant decrease from post 3.9 to delayed-post test 3.6. As in the previous case, this was due to the facilities provided by the spreadsheet.

In the Pre-test the majority of them (70%) did step 1+2+3, while 30% of them did steps 1+2.

In the Post test nearly all of them (90%) did steps 1+2+3+4, while 10% of them did steps 1+2+3.

In the Delayed-post test also the majority of them (60%) did steps 1+2+3+4, while 40% of them did steps 1+2+3.

Thus, in pre-test students attempted to do steps 1+2+3. In the post test they did steps 1+2+3+4. In the delayed-post test they did the three steps and almost the last step.

In the Post and Delayed-post tests also the majority of them (75%) did steps 1+2+3+4, while 25% of them did steps 1+2+3.

Taking into consideration the mean of the scores of post and delayed-post tests they performed successfully steps 1+2+3 and almost step 4. Consequently, the students from a High level of background knowledge in physics made an excellent use of the spreadsheet in the Post and Delayed-post tests.

The above mentioned difference in the students' performance between the levels can be explained because steps 1+2 were essential, while steps 3+4 were for advanced use of the spreadsheet. The spreadsheet also facilitated the analytical and accurate construction of graphs (e.g. slope of a line and point of junction on the y-axis etc.). To do the same work by hand was hard, time-consuming and also required more training and practice (van Zee and McDermott 1987).

This research studied students' difficulties with regards to graphical representation in physics. A novice seemed to lack explicit knowledge about the proper shapes of curves. This was due to the lack of a basic knowledge of correct definitions of the quantities and from a lack of the ability to calculate and plot these quantities (van Zee and McDermott 1987, Pratt 1995).

As noted above, in this particular research the Low level students and nearly all the Middle level students (8 out of 10) did nothing up to the calculations while nearly all the High level students (7 out of 10) made good use of the spreadsheet in the Pre-test. An improvement in the students' graphing skills was facilitated by the use of the provided software, as also claimed by van Zee and McDermott (1987) and Pratt (1995). They explored the software graphing facilities and made mathematical connections between their data and their graphs, developed their understanding of graphs and therefore drew inferences on relationships between electrical concepts.

van Zee and McDermott (1987) proposed that an emphasis on the development of both concepts and graphing skills must be given. This happened in the designed software shown by the students' answers to Question 16 of the Questionnaire - which is referred to the outcomes of the software.

Consequently, students of the low and the middle level gained the most benefit and students of the high level the least from the use of spreadsheet and from graph drawing. This agreed with students' comments in Question 16 of the Questionnaire, in which 14 out of 30 students claimed that they had gained graphing skills (2 of them were in High level background in physics, 5 of them were in Middle level and 7 of them in Low level).

b2) <u>The differences between mean score of all students' levels of background knowledge to their mean score of each level of students' background knowledge in physics</u>

The students' mean scores of Low, Middle and High level of the background knowledge in physics were for each test:

	Pre	Post	Delayed-post	Post+Del
Mean Score	1.2333	2.9666	2.6	2.7833

The differences between the students' mean scores and the mean scores of Low, Middle and High level students were for each test:

	Pre	Post	Delayed-post	Post+Del
Low	1133% (1.233-0.1)/0.1	48%	30%	39%
Mid	37% (1.233-0.9)/0.9	1%	18%	10%
High	54%(1.233-2.7)/2.7	24%	28%	26%

The above results showed that:

1) As previously mentioned (in Questions and Explanations), the differences between all students' mean scores for Exercise and the mean scores of each level students in each of the tests have also been remarkably reduced from pre to post and delayed-post test.

2) The differences ranged from 10% (Middle level students) to 39% (Low level), while from 37% (Middle level students) to 1133% (Low level) in the Pre-test.

3) The smaller the differences the greater the homogeneity. Similarly, not only with respect to the section above but also to the previously mentioned remarks on Questions and Explanations, the students' population became more homogeneous in their graphing skills.

b3) <u>Comparing the slopes of Line Chart graphs</u>

In addition, some of the remarks previously mentioned were also presented in fig. 4-14, fig. 4-16. The slopes of lines from pre to post test were greater while from post to delayed-post test were smaller. This means that there is a smaller difference in the students' performance, at all levels, from the Pre-test to Delayed-post test (fig. 4-15).

Comparing the graphs ExerPre=f(level), ExerPost=f(level) and ExerDel=f(level) (fig. 4-17, fig. 4-18, fig. 4-19, fig. 4-20) the slope of lines decreased from 1.3 to 0.95 to 0.8 respectively while the graph lines moved up to higher scores from pre to post test. The line graph of delayed-post test was approximately on the same level with post test.
Thus, with reference to the graphing skills, the student population became more homogeneous in post and delayed-post tests than it was in pre-test.

c) Concluding Remarks on the Exercise

1) In general, students' performance on the exercise was better in the Post and the Delayed-post tests than in the Pre-test while their performance had a small but significant decrease in the Delayed-post test.
2) The greatest decrease was by the students from a Middle level of background knowledge in physics and the least decrease by High level students. This can be explained by the fact that the software provided facilities for an accurate construction of a graph [e.g. slope of a line and point of junction on the y-axis etc. (fig. 4-13 and fig. 4-14).
3) Students from a Low level in Physics background gained the most benefit, students from a Middle level less and students from a High level the least in the use of spreadsheet and in drawing graphs. Their performances tend to have smaller differences among levels from Pre-test to Delayed-post test (fig. 4-15). Hence, the homogeneity of the student population increased.

4.1.4 GENERAL CONCLUDING REMARKS ON QUESTIONS, EXPLANATIONS AND EXERCISE

1) All students benefited by using the software, some more than others.
2) Referring to their background knowledge in physics, students from a Low level benefited more; students from a Middle level benefited less; students from a High level benefited least.
Similar results came from the evaluation of a physics multimedia resource (SToMP) by Watkins, Augusti and Calverley (1997).
3) There was a small decrease in the scores from post to delayed-post test. In both cases of Explanations and Exercise, the decrease was small but significant.
4) With reference to their background in physics, the decrease was greatest for the students from a Low level; less for the students from a Middle level; and least for the students from a High level background in physics.

5) Homogeneity of the student population became greater from pre to delayed-post test.

4. 2 DISCUSSION ON THE RESULTS FROM THE QUESTIONNAIRE

The questionnaire, which referred to both technical and subject domains, drew the general conclusion that the majority of the students gave positive answers and also positive explanations to their answers in the questionnaire.

As to whether they enjoyed using the software, 29 out of 30 students agreed they had and only one was undecided without giving any comment or explanation. There were no negative comments.
When they were asked to compare the software to teaching, 29 out of 30 students gave positive comments and only one student answered negatively "Too basic".
Finally, when they were asked to mention whether they had gained something from the software, similarly as before, 29 out of 30 students gave positive comments and only one student did not give any answer. In this case, even students, who had previously made negative comments on other questions, agreed and explained their answers positively.

4. 2. 1 LOGICAL SEQUENCE OF DATA (Table 4-Q1)

The majority of the students (24 out of 30) agreed that the software provided a logical sequence of data analysis by claiming that "it goes by steps from easier questions in the beginning to difficult at the end". Others (8 out of 30 students) centred on the existence of "the same logical sequence in the theory".

Students' comments were as follows:
"It (the software) goes through by steps ... from easier to difficult questions at the very end ... same with the theory, as well" (No 2H)
"The first few questions were simpler than the last few. The latter questions answered with knowledge gained by doing the first few questions" (No 4M)
"The problems gradually became harder ... it follows a logical sequence" (No 16L)
4 out of 30 students were undecided. One gave no explanation. Three gave negative comments, such as "there was a logical sequence but only in some subjects" (1 student) or they were "not sure if software was very logical" (1

student) or they were "not sure about its (software) HyperCard style" (1 student).

2 out of 30 students disagreed. One of them claimed that "information was repeated" and the other disagreed too but gave no explanation.

4. 2. 2 EXPLORATION OF INFORMATION (Table 4-Q2)

The majority of the students (26 out of 30) agreed that the software provided activities which encouraged learners to explore the information. They claimed that the theoretical feedback especially encouraged learners, and emphasised that the presentation or layout led in "a remarkable way through the animated pictures and smart illustrations". 11 out of 26 students reported that these facts helped them to better understand the electrical concepts and to enjoy learning. Some others (8 out of 26) mentioned that these activities were also provided "simply just by pressing a button".

In their attempt to find the path to the needed information:

a) 9 out of 26 students supported that these activities were provided by clicking onto the theory button

b) 17 out of 26 students claimed that you could first use the "Hints" button for some help and, also the button was referred to the theoretical feedback (called the theory button) which gave further help.

Students' comments follow:

"It makes things easier to understand and enjoyable to use with the theory (button)" (No 2H)

"If you don't know the answer simply pressing a button will give you some ideas ... the "Hints" or the theory button..." (No 8M)

"If stuck on a question you can click on "Hints" or ... go back into the package (using of the theory button) read about it ... then answer the question" (No 15L)

4 out of 30 students were undecided.

Two of them gave no explanation and two others said that "it may generate interest (to explore information) but not always".

4. 2. 3 PLAN OF SOLUTIONS TO THE QUESTIONS (Table 4-Q3)

The majority of the students (19 out of 30 students) agreed that the software provided activities which encouraged them to plan their solutions systematically. They also claimed that the text field "Why do you say that?" forced them to write down their plan, step-by-step. They added that they could click on the "Hints" and the theory buttons for further help. With regards to the theoretical feedback they mentioned that "theory was easier to understand and enjoyable to use" and "good illustrations helped to understand" and therefore to write the plan for the solution of a problem in details. In particular:

a) 10 of them claimed that the text field, the "Hints" and the theory buttons encouraged them to do that.

b) 8 of them claimed that the text field and the theory button encouraged them to do that.

c) 1 of them gave no explanation.

Students' comments:
"in the text field below ... you were asked to write systematically the solution. You could have some help from "Hints" and more help from the theory" (No 27L)
" Because the software "asks" the students not only to answer but also to explain their answers ... with help from the theory if it was needed" (No 19H).

8 students were undecided. Seven of them gave no explanation and one student mentioned that "some questions were confusing".
Three students disagreed. One of them claimed that "it (the software) needed to have a more logical progression" and the rest mentioned that the Questions were "guessing".

4. 2. 4 EXAMINATION (PROBE) OF STUDENTS' THINKING (Table 4-Q4)

The majority of the students (25 out of 30) agreed that the software provided activities which encouraged them to think about their reasoning (e.g. to define a problem, to plan a solution etc.). When asked about this aspect:

a) 9 out of 25 mentioned that firstly the text field "Why do you say that?" provoked them to examine their thinking; secondly the "Hints" and theory buttons helped to do that.

b) 11 out of 25 claimed that the hints and theory buttons did help them to think about their reasoning. So, 2 out of 25 supported that the theory button also helped to do that.

c) 2 out of 25 gave no explanation.

d) One agreed saying that "careful attention is needed to complete the questions".

Some students' comments:
"The questions force you to think and to plan your solution ... help is provided by "Hints" and theory (buttons) if needed" (No 4M)
"By asking me how I came to my answer. I was encouraged to do this by the text field below, by the "Hints" and the theory buttons" (No 24L)

4 students were undecided but they did not give any explanation.
One student disagreed and mentioned that there was "no coherent path along to follow".

4. 2. 5 ATTEMPTS FOR ALTERNATIVE SOLUTIONS TO QUESTIONS
(Table 4-Q5)

The majority of the students (25 out of 30) agreed for the following reasons that the software encouraged them to try alternative solutions to the questions:
1.- There were multiple choice answers
2.- They could have two or three chances at finding another solution if their answer was wrong
3.- There were two correct answers in some questions
With reference to the above mentioned reasons:

a) 4 out of 25 students supported all the mentioned reasons

b) 19 out of 25 students supported the first and the second reasons

c) 2 out of 25 students supported the third reason

Some students (10 out of 25) also reported in their comments that they could "keep trying !" and others (2 students) emphasised the effect of being able to go to the theoretical feedback in which there were "various working examples" and to which they could find an alternative solution.

Students' comments follow:
"the student had a second choice which was helpful in re-assessing the question" (No 16L)
"keep trying till you get it right!" (No 6L)

"when you are not sure of an answer you can try different solutions. It makes you think why you might be wrong" (No 4 M)
"It (the software) does encourage you to try alternative solutions to the Questions, by giving various working examples" (No 17H].

5 students were undecided but they did not give any explanation.

4. 2. 6 LOCATION AND CORRECTION OF STUDENTS' MISTAKES
(Table 4-Q6)

The majority of the students (25 out of 30) agreed that the software encouraged them to use systematic methods for locating and correcting mistakes. They mentioned that "if a mistake was made then it was possible to find out what had gone wrong by clicking onto the "Hints" and the theory buttons".
Thus, students supported respectively:
1.- Only theory button (8 students)
2.- Hints and theory buttons (17 students)
Some of them (4 students) emphasised "the availability of the theory which was the best way in order to correct a mistake".

Some of their comments were, as follows:

"Thought is provoked by correction a wrong answer... simply by pressing the "Hints" and/or the theory button" (No 14M)

"The software informed you if your answer was wrong. Then you could click on "Hints" or theory buttons. So from the provided theoretical feedback you could choose the topic that you needed and you could correct your mistake" (No 5M)

"You have got tries. So you can think the problem carefully. By clicking on "Hints" or going to the theoretical feedback provided, you could find out your mistakes and you could correct them" (No 20H).

4 students were undecided.
Two of them gave no explanation and the other two said that they were "undecided with reference to the use of systematic methods" for locating and correcting mistakes.
One student disagreed claiming that "it could have been more systematic".

4. 2. 7 BREAKING DOWN A PROBLEM (Table 4-Q7)

The majority of the students (18 of them) agreed that the software encouraged them to break down complex problems into smaller and simpler problems. Thus, they emphasised that :

1.- Both theory and questions were broken into smaller and simpler parts (4 students)

2.- The Questions were broken into smaller parts (10 students)

3.- The theory was broken into smaller parts (4 students)

Students' comments are noted below:

"In many questions it (the software) simplified matters by breaking down the questions into simpler parts -I mean sub questions. For example, question 1 was broken down into four sub questions, question 5 was broken into two etc. ... the same theory was in detailed parts" (No 30L)

"The software showed in detail smaller components of a big picture -he was referred to the structure of concepts in the theory- ... e.g. resistance was divided into smaller and simpler parts such as: the concept of resistance, Ohm's Law, relationship between resistance and temperature, relationship between resistance and its length, its cross-section and its material and others, mainly presented in the form of animated pictures" (No 17H).

11 students were undecided. Ten of them gave no explanations and one mentioned that "only in some cases, it (software) did so".

One student disagreed because "the wording was not clear".

4. 2. 8 COLLABORATIVE LEARNING (Table 4-Q8)

The majority of the students (19 out of 30) agreed that the software promoted collaborative learning and shared problem-solving.

Thus, students mentioned that:

1.- They talked with others (19 students)

2.- They talked with others and took joint decisions (17 students)

Some of the students' comments were:

"Although everybody worked on his own computer he could have a talk with other students all around ... to exchange ideas ... to get help from others in making a decision" (No 5M)

"Fellow students were able to explain problems" (No 6L).

7 students were undecided but they gave no explanation.
Three students disagreed. They claimed that a computer promoted individual learning.
Another student also disagreed strongly claiming that: "Working with a computer tends to isolate the student ... not to encourage collaborative learning" (No 4M).

4. 2. 9 EASE OF OPERATION (Table 4-Q9a)

The majority of the students (25 out of 30) agreed that the software was easy to use. No special knowledge and skills were needed. They mentioned that the operation of the software was simple, such as "simply pressing a button", and its environment was user-friendly.
The students' answers to Q 9a were:
1.- No knowledge on computers (19 students)
2.- No skills on computers (14 students)
3.- Simple operation (9 students)
4.- User-friendly environment (15 students)
5.- Clear lay-out (2 students)

A typical and repeated comment was:
"It was easy, ... just pressing buttons, ... simple operation, ... no special knowledge and skills on computers were required" (No 26L).

Two students were undecided. One of them gave no explanation and the other mentioned that the software was "not always easy".
Three students disagreed. One of them gave no explanation, the second one reported that "difficulty from buttons existed in some cases" and the third one reported that the software went "round in circles".

4. 2. 10 FUN WITH THE USE OF SOFTWARE (Table 4-Q9b)

Nearly all students [29 out of 30 = 25A + 4SA] agreed that they enjoyed using the software.
Even 4 students, who disagreed with most of the other questions, in this case agreed and gave positive explanations (No 11L, No 12M, No 13L and No 14M).

Students claimed that the smart illustrations and animated pictures introduced them to another way of thinking (reasoning) which helped them to understand the electrical concepts by linking the unfamiliar and the abstract information to the familiar and the concrete information (use of models and analogies on electricity). While using the software they had fun with electricity. They also mentioned that they enjoyed the challenge by solving problems. Some students supported the fact that the theory was directly available when needed, which helped to answer the questions.
Thus, students' explanations were categorised as:
1.- Smart illustrations and animated pictures (23 students)
2.- Fun with theory (18 students)
3.- Another way of thinking (reasoning) which promoted an easier understanding (11 students)
4.- Enjoyed a challenge (11 students)
5.- Theory directly available where needed (3 students).

Students' comments were as follows:
"Unusual and pleasant way to solve problems, ... and smart illustrations ... you had fun with electricity -I mean the theory- which was directly available and when you needed it" (No 20H).
"I always enjoyed a challenge from solving problems ... enjoyed learning electricity and computing with such smart and funny illustrations and animated pictures ... I learned another way of reasoning ..." (No 18H).

Only one student was undecided without giving any explanation.

4. 2. 11 INTEREST IN USING THE SOFTWARE (Table 4-Q9c)

The majority of the students (26 out of 30 = 21A + 5SA) agreed that the software was interesting because of:
1.- The animated pictures and illustrations (17 students)
2.- The theory was easily available (directly found), taken and fully analysed (16 students)
3.- Another way of thinking provided by the software (use of models and analogies) (10 students)
4.- The way of presenting the information by the software (9 students)
5.- Lots to see and theory to put into practice (3 students)
6.- Good experience (1 student).
All the above mentioned stimulated their interest in the subject domain.

Some of the students' comments follow below:

"Knowledge (the theory) could be easily found and in details" (No 2H).

"If your answer was incorrect then the software itself motivated you to have another try by exploring the information from the theory directly and in detail ... The information was presented in an interesting and novel way ... it was another way of thinking by linking the unknown to the known" (No 7H).

Three students were undecided. However, two of them gave no explanation and one mentioned that the software was interesting "to some degree".
One student disagreed, claiming that the software would be interesting if it was "in shorter sessions".

4. 2. 12 PRESENTATION OF ELECTRICAL CONCEPTS (Table 4-Q10a)

The majority of the students (23 out of 30) claimed that the software was useful for presenting the essential concepts on electricity because it introduced different ways of thinking (about these concepts). This in turn helped them to understand better and explain better the concepts. Students emphasised the illustrations and animated pictures which were considered useful and "enlightening" for learning. They mentioned that they were smart and funny and therefore they enjoyed learning about electricity. Some supported the way of presenting the information as being important in understanding the subject domain (electricity).

Thus, students' comments were categorised:
1.- Theory, illustrations and animated pictures (9 students)
2.- Different ways of thinking (14 students)
3.- Way of presenting information (6 students)

Some students' comments were such as:

"The graphics (illustrations and animated pictures) in the theory were very good, smart, funny and enlightening" (No 6L).

"Illustrations and animated pictures were smart and pleasant ... introduced another way of reasoning" (No 8M).

"These (electrical) concepts were presented in a different way, they were easier and helped students to understand and explain them" (No 18H).

Three students were undecided. Two of them gave no explanation and one claimed that it was useful for presenting these concepts "in a broad sense".

Four students disagreed. The first of them considered that it was "too basic", the second mentioned that the software presented "simple concepts not difficult", the third reported that he preferred to use his notes and the fourth claimed that it would be useful for presenting these concepts if it was "in shorter sessions".

4. 2. 13 **INCREASE OF KNOWLEDGE** (Table 4-Q10b)

The majority of the students (25 out of 30) agreed that the software was useful for increasing knowledge of these essential electrical concepts. The most important reason was the availability of the theoretical feedback when needed and which was well-done and enlightening. They supported the idea that an increase of their knowledge was caused by the introduction of another way of reasoning came from the design of the software. Illustrations and animated pictures were also another factor for the development of their knowledge on these concepts and were also correlated to the introduction of another way of thinking.

Thus, students' answers were categorised:
1.- Direct use of well-done and enlightening theory (11 students)
2.- Another way of thinking (9 students)
3.- Illustrations and animated pictures (6 students).

Some students' comments follow:

"I was able to pick up the information from the theoretical part that I needed, when it was needed" (No 2H)

"It was another way of reasoning ... availability of the theory when needed " (No 8M)

"Theory was well-done and enlightening" (No 6L).

Two students were undecided who did not give any explanation.
Three students disagreed. Two of them "preferred their notes" and the other student mentioned that it was "too much, it would be useful for increasing knowledge if it was in shorter sessions".

4. 2. 14 **MOTIVATION** (Table 4-Q10c)

The majority of the students (22 out of 30) agreed that the software was useful for stimulating interest in these concepts because of:

1.- Giving more information from a fully analysed theory and in a simple way (13 students)
2.- Illustrations and animated pictures which provided a nice presentation of these concepts (12 students)
3.- Another way of thinking (reasoning) provided by the software while studying the theory (10 students)
Some students also mentioned that all the above helped them to enjoy studying these concepts with this way of learning.

Students' comments follow regarding the usefulness of the software:

"... because of the way information was presented (illustrations and animated pictures) ... it introduced another way of thinking and enjoying while studying the concepts" (No 10H)

"... because information was provided when it was needed and the concepts were fully analysed and presented in a quite simple way" (No 19H).

5 students were undecided. Three of them gave no explanation and two of them mentioned that it was not particularly useful for stimulating interest.
Three students disagreed. One of them made no comments, the second mentioned that he preferred his notes and the third claimed that "it would be if it was in shorter sessions".

4. 2. 15 MORE TIME (Table 4-Q11)

The majority of the students (20 out of 30) agreed that they would like to spend more time using the software to study and to better understand the theory. Some students claimed that "theory helped them to learn another way of thinking (reasoning) by linking the familiar knowledge (the known) to the unfamiliar (the unknown). Some others mentioned that the theory was "interesting and fun". Some of them would also like to study the software, i.e. HyperCard techniques, and only one student would like the questions to be repeated.

The students' reasons to spend more time using the software were:
1.- Theory (20 students)
2.- Theory + software (6 students)
3.- Theory + questions (1 student)
4.- Another way of thinking (4 students)
5.- Interesting and fun (4 students)

Some of the students' comments were:

"To get some more information for the software (HyperCard) and the electricity concepts both of which were presented in a very interesting and pleasant way" (No 21H)

"I feel that by using the software more often you could use it better and faster and to get more out of it ... I enjoyed it because it presented a new way of reasoning bridging the unfamiliar to the familiar concept" (No 4M).

Three students were undecided and gave no explanation.
Seven students disagreed. Four of them made no comment and three preferred to work with paper and pencil.

4. 2. 16 QUESTION 12 (Table 4-Q12)

Regarding question 12, students were asked to mention ways in which they had previously learnt about electricity. All of them had topped up their knowledge mainly with lectures, practicals, tutorials and studying relevant textbooks.

4. 2. 17 COMPARISON WITH PREVIOUS TEACHING (Table 4-Q13)

In comparison with teaching methods that students had previously encountered they expressed various opinions. The majority of them claimed that the way in which information was presented stimulated interest in the subject domain, by linking unfamiliar to familiar concepts. Thus, they gained a "deeper" understanding and consolidated their knowledge on the unfamiliar concepts. A result of that was their ability to explain them to others. According to Ganiel and Eylon (1987) and (1990) this fact derives from a "deeper" and "proper understanding" of the concepts because students think in terms of the aspects not only of the quantitative relationships but also of the functional relationships and the processes and macro-micro relationships among the variables in an electric circuit.

Some students also claimed that theory was available when needed. Some students also considered the software as a supplement to teaching that they have previously encountered.

Positive explanations (comments) were expressed:

a) By students from a High background level of physics:

"...it stimulates their (students) interest in the subject (electricity); it was unusual and pleasant, enjoyable way of presenting these concepts (of electricity)" (No 20H)

"...it was something unusual that kept me interested in studying this subject and learn much more about the software (means HyperCard)"(No 21H)

"...difficult concepts on electricity were presented in a different, easier way, helping students to understand them (in depth) ... combining (linking) unfamiliar , abstract concept to familiar, concrete one... helped a lot! It increased my knowledge in concepts I thought I could not learn more.." (No 22H)

b) By students with more negative comments on the questions of the questionnaire. In the question they expressed positive comments such as:

"Good idea ! I enjoyed it" (No 11L, No 12M, No 13L).

Thus, overall students' positive answers were categorised:

1.- Presentation of information in a remarkable way (19 students)
2.- Good idea ! I enjoyed it (12 students)
3.- Deeper understanding + possibility to explain (10 students)
4.- Stimulated interest on the subject domain (9 students)
5.- Availability of the theory when needed (8 students)
6.- Software as a supplement of teaching (5 students)
7.- Consolidation of knowledge (2 students)

One student gave a negative comment "Too basic !".
In general, he had a negative view on the software as per his answers and comments in the questionnaire. However, further on, in question 16 he answered that he had gained some knowledge on circuits that he had not properly studied.

4. 2. 18 QUESTION 14 (Table 4-Q14&15)

Regarding question 14, students were asked whether they had done any extra work on electricity in the last month. The majority of them (22 out of 30) had attended the first year course on electricity while 8 students had attended a session (duration three hours) just as a revision course on electricity.

4. 2. 19 QUESTION 15 (Table 4-Q14&15)

Regarding question 15, students were asked what kind of extra work on electricity had been done in the last month. The majority of them (22 out of 30) had attended classes on electricity in the form of lectures and had done laboratory work. They had also studied their notes and relevant textbooks.
8 students had done nothing more than the revision course.

4. 2. 20 RESULTS FROM THE USE OF THE SOFTWARE (Table 4-Q16)

Nearly all students (29 out of 30) gave positive comments to the question.
The majority of students claimed that they had learnt a new way of thinking about electricity concepts. A significant number of them also reported that they had gained a deeper understanding and more detailed information on these concepts. Thus, they learned more on the subject domain and could also explain better to other students (Ganiel and Eylon 1987 & 1990). Many students mentioned that they consolidated their knowledge on these electrical concepts, especially on topics such as circuits, resistors in series and in parallel etc.

Many students also mentioned that they had gained computing skills by using HyperCard. In a discussion with the researcher the students expressed how they found the software useful and helpful for drawing inferences in various topics. Nearly half the students (14 out of 30) mentioned that they gained skills on drawing graphs through the provided spreadsheet (14 = 2 High level of background in physics + 5 Middle + 7 Low). Consequently, students from a Low and Middle level of background knowledge of physics benefited more than students from a High level, as previously mentioned in the discussion of the results of the Exercise.

Thus, students' positive comments were categorised as:
1.- Another way of reasoning (19 students)
2.- More learning and clearer info + better and higher understanding + to explain (17 students)
3.- Skills in drawing graphs (14 students)
4.- Consolidate their knowledge (13 students)
5.- Computing skills on HyperCard (12 students)
6.- Talk with researcher + draw inferences on topics (11 students)

One student did not make any comment for this question.

It is worth mentioning that:

a) Even those students, who made negative comments in previous questions, were positive in this question. For example, the student (No 14M) who had mainly made negative comments, claimed in this question that he had gained "knowledge from general mistakes made by not studying properly some topics e.g. circuits etc.".

b) Positive comments came from students with High level of background knowledge in physics such as:
"The software helped me to refresh and consolidate electronic theory details in my mind.. it also showed me a better way to solve a problem; so I gained another way of thinking..."(No 19H)
" ...I liked the combination (link) of the unfamiliar knowledge (abstract subjects) to the familiar (concrete) one... also the discussion with the researcher helped me to find another way of reasoning... and to draw inferences on the abstract concepts" (No 20H)

c) Positive comments also came from students with Low level of background in physics such as:
" an insight into another method of teaching, a better understanding of the basics on electronics due to the way of presenting these concepts linking abstract to concrete (concept), e.g. voltage dividers and animals model, resistance and hosepipe model..." (No 6L).

4. 2. 21 CONCLUDING REMARKS ON THE QUESTIONNAIRE

1) It should be noted that those students, who had given negative comments to most of the questions (from the questionnaire), had given positive comments to at least two of them (question 13 and 16).
One of them only gave positive comments in question 16.
Thus:

a) Student No 11L was undecided and gave no explanation. He answered by ticking only one "Agree" on question 9.b and wrote the comment "Enjoyable illustrations".
However, his answer to question 13 was "Good idea ! I enjoyed it" and to question 16 he stated that he had gained "some knowledge from mistakes on some topics such as circuits".

b) Student No 12M gave more negative than positive comments. To question 11 he answered that he "prefers paper and pencil solutions to these problems".

However, his answers to question 13 was "It was a good idea, a good experience. I enjoyed it!" and to question 16 he said that he "consolidated basic knowledge of what he had already been taught".

c) Student No 13L gave more "undecided" answers with no explanation and some "disagree" answers.

However, his answers to question 13 was "Good idea ! I enjoyed it" and to question 16 he "consolidated electrical concepts and graphing skills (with the use of the provided spreadsheet)"

d) Student No 14M gave more undecided answers with negative explanations. His comment was also negative to question 13, his reply was "Too basic".

However, in question 16 his comment was that he had gained "knowledge from general mistakes made by not properly reading some topics e.g. circuits etc.", as already mentioned previously.

From all the above mentioned the conclusion is that the students claimed that they had learnt some electrical concepts. All of them -except one student- also enjoyed this way of learning.

2) In some of the answers to questions (9, 10, 11, 13 and 16) a considerable number of students' comments were frequently repeated; this indicates what kind of influence the software had upon the students' reasoning, learning and attitudes to the software.

Thus, with regards to:

a) Illustrations and animated pictures

In questions 9 and 10, many students claimed that the smart illustrations and animated pictures supported their learning of electrical concepts in the framework of the use of models and analogies, which introduced them to another way of reasoning.

In his research findings, Hartel (1993) also emphasised the power of illustrations and animated pictures on learning. He claimed that "animated graphics should give a better leverage to uncover hidden relations, to separate co-existing processes and to give time for a stepwise reconstruction". As previously mentioned in Chapter 2, such work stimulated the students to apply hypothetico-deductive thinking to genuine problems. In addition, illustrations and animated pictures supported imagery and visual learning (Hammond 1971, Reif 1986, Nielsen 1990). According to Hartel (1985 & 1993) and Psillos & Koumaras (1993), especially with the use of a computer, they

encouraged mental processes, such as receiving, storing, processing, retrieving, applying information.
Thus:

Question	Students	Students (%)
9.b	23	77%
9.c	17	57%
10.a	9	30%

b) Another way of thinking (reasoning)

In questions 9, 10, 11, 13 and 16, the students reported that the software introduced to them another way of thinking in the form of illustrations and animated pictures by linking the abstract (electrical concepts) to the concrete information (models and analogies). This promoted a better understanding of these concepts because of the "concretization of the notion" (Joshua and Dupin 1993). As previously mentioned in Chapter 1 and Chapter 2, many recent researchers support the idea that using models and analogies is of great importance for teaching & learning science.
Furthermore, the students also considered the use of the software interesting and enjoyable. The motivational features of the instructional design had additional positive effects on students' learning processes.
Thus:

Question	Students	Students (%)
9.b	11	37%
9.c	10	33%
10.a	14	47%
10.b	9	30%
10.c	10	33%
11	4	13%
13	19	63%
16	19	63%

In addition:
In question 13, the students stressed the fact that the introduced way of reasoning was "enlightening" in helping them to understand the concepts in depth.
In question 16, many of them also specified various forms of learning, such as skills on drawing graphs, computing skills and also features regarding the quality of learning, such as consolidation of knowledge, supplement of teaching, enjoyment of learning, understanding in depth.

The above mentioned facts proved some of their attitudes to the software, such as it being a user-friendly, enjoyable and exploratory learning environment. A detailed analysis is presented in the next section (Students' attitudes to the software and learning).

c) Fun with the use of the software

In questions 9, 10, 11 and 13, many students claimed that in using the software - especially the theoretical part - they had fun. Some also reported that they had enjoyed a challenge from solving problems and learning in general. Similar research findings were stressed by Cosgrove, Osborne & Carr (1985) Robertson et al. (1995).

Thus :

Question	Students	Students (%)	
9.b	18	60%	fun with theory
9.c	11	37%	enjoy a challenge
10.a	9	30%	enjoy learning
10.c	12	40%	enjoy learning
11	4	13%	fun with software
13	12	40%	enjoy software

According to the students' comments and based on cognitive theories of motivation, as mentioned in Chapter 2, the software created a suitable environment for learning, and enhanced students' intrinsic motivation hence allowing individualised learning (Lens 1994).

d) Ways of presenting information

In questions 9, 10 and 13, students supported that the way of presenting the information was important in understanding essential concepts on electricity. A considerable number of students considered it as a nice presentation. Furthermore, the majority of them claimed that the presentation of the electrical concepts became remarkable, in the form of models and analogies, which were of importance in this sort of presentation for learning these concepts. Similarly many researchers (Gentner and Gentner 1983, Cosgrove, Osborne and Carr 1985, Dupin and Joshua 1985 & 1989, Tenney and Gentner 1984, Treagust 1993, Jubin and Smith 1994, Wild 1996, Sapwell 1996) considered that one of the most powerful ways to understand a physical system is by using models and analogies.

Thus:

Question	Students	Students (%)	
9.c	9	30%	
10.a	6	20%	
10.c	12	40%	nice presentation
13	19	63%	in a remarkable way

Based on the students' comments (e.g. nice presentation, in a remarkable way), such a presentation of the information made learning more attractive. The motivational effects of the software on their learning processes (curiosity, attention, mental effort and involvement, mindfulness etc.) worked and improved students' learning performances in post and delayed-post tests.

e) Theory directly available and fully analysed

In questions 9, 10 and 13, students supported the proposition that the theoretical part of the software was not only directly available when needed, but also fully analysed and presented in a simple way. Similar research findings were reported by Ganiel and Eylon (1987), and Grob, Pollak and Rhoneck (1993) for their computer based training system.

Thus:

Question	Students	Students (%)	
9.b	3	10%	directly available
9.c	16	53%	directly+fully analysed
10.b	11	37%	directly+fully analysed
10.c	13	43%	directly+fully analysed
13	8	27%	directly available

Blodin (1993) also supported the availability of theoretical feedback and proposed that the success of learning sessions was dependent on the information gleaned by students (which information and when).

f) Interest in the use of the software

In general, in question 9 students claimed that the software was interesting because of the animations and illustrations, the introduction of another way of reasoning, the way of presenting the information. All of them agreed with the researchers' remarks as already previously mentioned.

As in Schultz et al. (1987), interest in the use of the software also came from the availability of theoretical feedback which was the information gleaned by students.

In question 13, nearly half of the students reported that the software also stimulated their interest in the subject domain, as a result of the motivational effects of its instructional design, with a positive impact on learning (Lepper and Malone 1987, Lens 1994). Similar research findings were claimed by Ganiel and Eylon (1987), and Schultz, et al. (1987).

In question 11, a significant number of students wanted to spend more time on the theory and others wanted to spend more time on the computer because the software was interesting and fun. Students' comments indicated the influence of the software on their psychological and cognitive behaviour. Thus:

Question	Students	Students (%)	
9.c	17	57%	animat+illustrations
9.c	16	53%	directly+fully analysed
9.c	10	33%	way of thinking
9.c	9	30%	presentation info
11	20	67%	more time in theory
11	4	13%	way of thinking
11	4	13%	interesting+fun
13	9	30%	interesting theory

g) Shorter sessions

In both questions 9 and 10, only one student claimed that the software would be useful for the presentation of these kinds of concepts if it was in shorter sessions. In contrast, a significant number of students would prefer to devote more time doing it, being aware of the outcome of their learning process. This fact agreed with Atkinson (1978), Parker & Lepper (1992) and Robertson et al. (1995). The researchers emphasised that this outcome is dependent not only on how efficient the learning process was but also on how much time was devoted to it.

However, when students were attending lectures, workshops and tutorials a computer laboratory with suitable equipment was required to be available at the same time. Consequently these limitations on both students and laboratory availability obliged the research to be undertaken in one three hour session, contrary to what Atkinson (1978) and Parker & Lepper (1992) proposed.

4. 2. 22 STUDENTS' ATTITUDES TO THE SOFTWARE AND LEARNING

Generally, students approved of the use of the software: "Good idea ! I enjoyed it!". Similar students' comments were reported by other researchers, as well (Cosgrove, Osborne and Carr 1985, Clement et al. 1987, Robertson et al. 1995). Thus, the software was considered as :

a) User-friendly learning environment

From the results of the Questionnaire, the students claimed that its environment was user-friendly and its operation was simple. They did not need to have special computer skills. As Lens (1994) claimed "being familiar with computers is for many of them an important prerequisite for the positive motivational and learning effects of CAL".

Because the software provided activities, the majority of students were encouraged to explore the information, such as: e.g. "If you don't know the answer simply by pressing a button will give you some ideas ... the "Hints" or the theory button" (No 8M). For more details you can see students' answers to the Questionnaire for the relevant Questions and Tables 4-Q 2, 4-Q 3, 4-Q 4, 4-Q 5 and 4-Q 6). They obtained a full use of buttons navigating through the stacks and exploring the information, especially in order to gain further details from the theory so as to correct their mistakes.
They also gained skills in HyperCard and drawing graphs. In general, they considered that the use of the software was easy.

In this research the students also emphasised one valuable facility - this being the availability of theory when needed. Thus, the software acted as a tutor for the students in such a way that it gave positive feedback as often as possible and immediately before & after the answers to the Questions & the solution of the software Exercise. They also liked the alternative solutions (multiple choice answers, 2 or 3 chances, two correct answers) provided by the software. Similar research findings were reported by Ganiel and Eylon (1987), and Schultz et al. (1987).

b) Motivating and enjoyable environment

The students agreed that the software was enjoyable and motivated their interest, as also claimed by Schultz et al. (1987) and Robertson et al. (1995) for their software. Furthermore, in their research not only Lepper and Chabay (1985) but also Lens (1994) emphasised that computers can be good motivators, as they individualise the learning programme so that even young pupils stay challenged. In this research, the software could also motivate students by inducing the right kind of feedback after success and failure. Similarly to Lepper et al (1993) the software provided effective emotional support to learning and in general positive feedback as often as possible and when needed by learners. The students progressively developed an intrinsic motivation for learning tasks, because according to Lens (1994) they could experience mastering, success, competence and progress in their learning tasks.

Consequently, making learning more fun could be an end in itself and might have positive effects on the learning process (Salomon 1985, Lepper 1985). However from a more applied point of view learning became more attractive so that students would spend more time doing it (Rand 1987).

c) Exploratory learning environment

In this research, the students emphasised the smart illustrations and animated pictures which introduced to them another way of reasoning and helped them to more easily understand electrical concepts by linking the unfamiliar and abstract information to the familiar and concrete one. Thus, they had fun with electricity and enjoyed the challenge of solving problems. Referring to the results of the Questionnaire, nearly all students (29/30) enjoyed the use of the software.

According to Clement et al. (1987) this kind of link could be used in order for difficult conceptual material to make sense to the student. Such a strategy promoted conflict between the information provided - mainly in the form of models and analogies - and the student's misconceptions, thereby encouraging conceptual change. Consequently, the students became internally motivated to understand and resolve cognitive conflict [Driver (1986), Closset (1985), Hewson and Hewson (1984)].

d) Environment stimulating interest and cognitive curiosity

In general, the screen layout and the structure of the software stimulated their interest. They made learning more attractive and showed that the students were intrinsically and extrinsically motivated to learn.
Similar remarks came from other researchers, such as Atkinson 1978, Rand (1987), Parker and Lepper (1992). Both students' intrinsic and extrinsic motivation developed, as did their cognitive curiosity and desire for deeper learning. Because of these motivational and learning effects, the majority of the students expressed willingness to spend more time studying the software (mainly the theory) in detail, with reference to the results of the Questionnaire.

Furthermore, concerning the students' representation and problem-solving in Basic Electricity, Rhoneck and Grob (1987) also studied the predictors of successful learning and their search was extended to additional psychological variables, such as individual and mutual student interest in the subject domain, and the creation of motivating environments. Thus, in the research these sorts of variables also supported students' cognitive development. With reference to the results of the Questionnaire the majority of the students mentioned that the software stimulated their interest in electricity and motivated them to enjoy studying these concepts. Similar students' reports were claimed by other researchers (Cohen 1984).

e) Environment "working psychologically" towards a cognitive development

In addition to the above, Wesley (1987) claimed that a cognitive physics course does affect the student positively. To effect this change:

1) the electrical concepts had to be organised to allow easy assimilation into a hierarchical structure within students' memories, as mentioned previously in Chapter 2. According to the Information Processing Theory of Learning, these concepts were most efficiently learned and retained as they were linked to existing general concepts already present in the cognitive structure of the learner.

2) it was of importance to create a suitable atmosphere for learning in which students were satisfied with what was achieved on the course, they were active participants in the whole process, and they did not feel bored and frustrated because they had help and encouragement.

As mentioned previously in Chapter 2, the design of the software was based on the organisation of the electrical concepts into a hierarchical structure in a student's memory mainly with the use of models and analogies. This had a strong influence on the students' psychological and cognitive behaviour.

As noted by Parker and Lepper (1992, p. 631) computers make it very "easy for instructional designers to create intricate, involving, and illustrated fantasy contexts into which educational activities can be embedded". Thus, for the software designed, according to Malone and Lepper (1987 p. 270), fantasy and imagery might have an important effect on intrinsic motivation and consequently, according to Parker and Lepper (1992), better learning performance.

f) Environment for achievement of a meaningful understanding

In the Pre-test phase, the concepts used by students to explain the operation of electric circuits showed several levels, as the students' population had different levels of background knowledge in physics. Only a minority of students operated on a higher level and were able to integrate all the concepts into a coherent picture in which they could associate the microscopic picture (electrons and forces between them) with the macroscopic parameters. According to Ganiel and Eylon (1987 & 1990) to achieve meaningful understanding of the electrical concepts and phenomena the presence of a micro-macro link is required to enable students to conceptualise the electric circuit as a system (Hartel 1985, 1987, 1993) and to "explain" concepts and phenomena occurring in electric circuits (Cohen 1984). Using the software allowed the students to achieve such a meaningful understanding, as demonstrated by their comments.

As mentioned in Chapter 2, Benedetti and Galileo and other researchers (Clement 1987, Petrie 1979, p.p. 460 - 461, Stight 1979, p.p. 474-485, Brown 1994, Ritchie 1994, Treagust et al. 1996, Wild 1996) argued that analogies and models - as thought experiments - were powerful methods of instruction and should act to increase student involvement and retention because they interacted with the knowledge.
Furthermore, according to students' repeated comments the thought experiments in the form of models and analogies introduced another way of reasoning, which supported a proper understanding of the electrical concepts.

g) Environment influencing on students' behaviour

According to Clement et al. (1987, p. 93) "Forming analogies is an important instructional technique ... Presenting the right analogy is not enough ... the student must also come to believe in the validity of the analogy".
This fact is an issue with regards to:

1) Students' repeated comments in the Questionnaire

In questions 9, 10, 11, 13 and 16 students stressed the introduction of another way of reasoning in the form of illustrations and animated pictures.

2) Change of students' wording

In the post and delayed-post tests students used expressions and wording which existed in the software instead of their own (See further details in later relevant section p. 251).
Both of the cases mentioned above also reveal the influence of the software on the students' cognitive and psychological behaviour. The result of this was their positive attitudes to the software, which in turn contributed to them learning about electricity.

Finally, similarly to Clement et al. (1987) and Laurillard (1993) the students considered that - as a result of their mutual interest in electricity - talking with other students and taking joint decisions on solving a problem established a better understanding of the subject domain. In addition, the talk with the researcher also helped them to draw inferences on the subject domain. In both cases, discussion encouraged students' active thinking so that learning was an interaction with knowledge rather than a transference from it (Clement et al. 1987 and Sutton 1996).

PART (II)

4.3 ANALYSES OF THE RESULTS FROM PRE, POST AND DELAYED-POST TESTS WITH REFERENCE TO THE SOFTWARE, THE QUESTIONS 1&6 AND THEIR EXPLANATIONS

4. 3. 1 PURPOSE OF THE QUESTIONS

Questions in general were drawn from studies reported in the literature. These included Shipstone (1984 p. 190, 1988 p. 308-310), Shipstone et al. (1988 p. 95) and Dzama (1992). Thus, their previous experience and knowledge became the reference point for further research on the subject domain.
The main purpose of the questions were:
a) Diagnosis of students misconceptions (pre-test phase)
b) Confrontation with their own ideas (post-test phase)
c) Change in their ideas using facilities provided by the instructional software (Hints and Theoretical feedback), and discussion with the researcher and other students (post-test and delayed-post tests).
In this part, the experimental results are analysed in relation to other researchers' results.

4. 3. 2 QUESTIONS' AND SOFTWARE DESIGN BASED ON MISCONCEPTIONS

Science educators and researchers have shown great interest in pupils' popularly acquired knowledge (Gilbert and Watts 1983). This existing knowledge has been called: misconceptions (Doran 1972, Helm and Novak 1983, Inowi 1983), alternative frameworks (Driver and Erickson 1983), children's conceptions/beliefs (Aguirre 1978, Albert 1978, Nussbaum and Novak 1976), cultural beliefs (Cole 1975, Odhiambo 1968), children's science (Osborne et al 1983) and children's early experience (Adenyinka 1983). Research in learners' scientific conceptualisation proves that these ideas are deeply rooted and not easily changed (Osborne 1983, Driver 1983).

Electricity is invisible and only its effects can be observed. This makes the ideas abstract and only through extended observation, discussion and experiment can students' understanding develop. Shipstone (1985) indicates that 50% of students 16 years old were able to predict the effect of adding bulbs in series to an existing circuit. Various researchers [Shipstone 1985, Osborne and Freyberg 1985 and the Assessment of Performance Unit (APU) 1984] have found that many students 15 years old use one or several 'alternative' working models, some of which explain some observed features of circuits but are mutually inconsistent. Some students seem to change their model depending on the problem they are solving, e.g. in Questions 1&6 all students changed their model while in Question 8 only some did.

According to Osborne (1981, 1982b, 1983), the most common alternative models are the following:
Model A (Unipolar)
Current leaves the battery at one terminal and no current returns to the battery because it is converted to light in the bulb (Osborne 1981, 1982 b, 1983).
Model B
Current leaves the battery at both terminals and it is used up within the elements of a circuit. Osborne (1981, 1982b, 1983) reports this as 'clashing currents' model, as mentioned previously in Introduction (Chapter 1).
Model C (Attenuation or unidirectional without conservation)
Current flows in one direction around the circuit and becomes gradually weakened as it goes so that later components receive less. This is named the "sequence model" (or sequential reasoning) (Shipstone 1984) and it is also previously referred to Introduction (Chapter 1).
Another expression of this model is that:
Current is shared between the components in a circuit. The current is not considered as being conserved (Unidirectional with sharing).
Model D (Unidirectional with conservation or Scientific)
The scientific view is similar to model C except that the current is conserved throughout the circuit (Osborne 1981, 1982b, 1983).

Research has also been conducted in science teachers' (Eylon and Ganiel 1983, Summers 1990, Kruger 1990, Cohen, Webb 1992) and University students' (Picciarelli et al 1991, Baxter 1995) concepts of current flow. The data show that there is a similarity of ideas held by adults. Thus, a more appropriate description of the understandings might be "popular science" rather than "children's science", as Webb (1992) claimed.

4. 3. 3 STRATEGIES FOR CONCEPTUAL CHANGE AND SOFTWARE DESIGN

It is clear that students have deeply ingrained ideas about the nature of electricity that they bring with them into science lessons (Waterhouse 1974).

They try to use these perceptions about the way the world works to make sense of their observations in science. Learning only takes place when students' observations are in conflict with their model and when they are encouraged to question their model, extending or modifying it as necessary. This is the main target of the software.

It is worth spending some time on crucial ideas for circuits, especially the constancy of current round a series circuit. This fundamental idea is often insufficiently emphasised and leads to an immediate paradox for many students: if the current leaving a battery is the same as entering it, then why does the battery ever run down? Unless students comprehend the ideas behind circuits, they will be unable to efficiently solve electrical problems in their daily life at home and at work.

Two strategies are relevant to these difficulties.

In the first strategy, students must be allowed to experiment in an open-ended way with circuit components and make changes to circuits. Practical problems must be set and students must find answers by themselves either with minimal guidance (multiple choice questions and minimal help from the "Hints" button) and/or with more help from the Software Part 1 which is the theoretical feedback of the software, as mentioned previously in the Description of the Software, Chapter 2. Thus, the use of the software usually causes conflict with students' mental models and they are encouraged to question their models modifying them as necessary, this in turn provides learning.

The second strategy is based on making current and its effects in a circuit visible, by using a concrete model for a circuit. In this case, concrete visual models and analogies of simple electrical phenomena are provided by the software. As mentioned in the Questionnaire, the students found it helpful to refer back to any model and analogy frequently, to point out differences and similarities and to ask other students to use the model themselves to simulate their own circuits in the questions, as an aid to problem-solving (Clement et al. 1987, Joshua and Dupin 1993, Grob, Pollak and Rhoneck 1993).

4. 3. 4 PROBLEMS IN UNDERSTANDING ELECTRICITY

Current

a) <u>Current flow and sequential reasoning</u>

As mentioned previously, the model of current flow which is implied by the "before and after" error is called the "sequence" model (Shipstone 1984). If a

change happens at a certain point in a circuit, then the current is influenced by the change when it arrives at that point, but not before. The naming of the model is because "a sequence of events is believed to occur as current flows around a circuit and spatial factors are at least as important as temporal factors in it" (Shipstone 1984 p.191). Responses of the "before and after" nature have been referred to as an indicator of a "time dependent model" for current (Riley et al. 1981), "sequential reasoning" (Closset 1983).
This approach arises from the assumption that any change, which takes place in a circuit, travels in the direction of current and not against it. The imagery evoked is very clear.
The model is a view adopted by almost all students at some stage and it is very persistent. The model is applied quite widely and consistently by those who hold it. Among students across all ages, Shipstone (1984 & 1988) showed that for those who had a unidirectional view of current, the incidence of the model varied and it was persistent in older ages. Similar results were presented by other researchers, as well (Karrqvist 1985).
In his latter study, Shipstone emphasised its persistence among many [7 out of 18 (39%)] physics and engineering graduates training to become physics teachers. Similar results were also presented by other researchers, as well (Picciarelli et al 1991).
In the same study, Shipstone's results supported the fact that both samples develop the "sequence" model independently of their other previous beliefs and models, when they face complex circuits.

From the scientific point of view, if a change is made then electromagnetic waves travel from the point of the change in both directions in the circuit. A new steady state is rapidly established in which currents and voltages in all parts of the circuit will have altered. Not only children but adults also assume that the change is transmitted only in the direction in which current is flowing. This misconception is a fundamental misunderstanding of the behaviour of circuits. It is also important because its incidence is high particularly in secondary education and it is persistent even among able students who have been studying electricity for about four years and at an advanced level.
As mentioned above, Riley et al. (1981), Cohen, Eylon and Ganiel (1983) and Grob, Pollak and Rhoneck (1993) also noted that students tend to adopt localised reasoning in a more general sense, ignoring the fact that an alteration at one point in a circuit has an effect upon the whole circuit. These types of reasoning are considered as the "sequence model". When current reaches a resistor then the strength of current must alter. So, the current leaving the resistor is different to the current entering it. According to Riley

et al (1981) and Unruh et al. (1997) the error of failing to conserve current is also a logical consequence of this model.

In this particular research, further evidence for the widespread nature of the sequential reasoning of current flow was produced. So, the students' persistent misunderstanding of the model of current flow was diagnosed. Their sequential reasoning was shown to exist as two types. There were some students who supported that the brightness of a bulb was dependent on its location between resistors in a series circuit either taking into account the Rtot of the resistors or not. The former case should be assumed as an intermediate step in the cognitive route until these students conceive the scientific model of electric current. With reference to the students' sequential reasoning an in depth analysis follows in later sections.

b) Current flow and energy flow

Researchers (Rhoneck 1982, Duit 1983, Aalst 1985, PLON project Netherlands 1979) claimed that many secondary school students describe current using terms such as "current is energy". Their view of the electric circuit is influenced by the energy view, while using the concept-words current and voltage. Their studies proved that even after extensive instruction, "current is a first order concept". Students tend to be "current-minded" rather than "voltage-minded" (Cohen et al. 1983, Steinberg 1985).

In this particular research, the students consider that:
1) The battery acts as a source of current
2) The current is used up while running through a resistor/bulb
3) The events caused by current are related to local interaction of the moving particles and the resistor/bulb.
However, the property of conservation of current is missing as a result of their sequential reasoning.

So, it is important for students to understand that electricity is merely a clean and convenient means of transporting energy from one point to another. This is done by transferring energy to electric charge which carries the energy to the load where it is transferred into the required form. The electric charge entering and leaving the device is always the same. No electric charges are used up. In the work for this thesis students were helped to adapt this concept by using models and analogies provided by the software. Further details are available in the section "Software design based on strategies to avoid misconceptions".

Potential Difference

a) Potential Difference and Current

The formation of an independent concept of pd. or voltage is a main objective in teaching basic electricity.

Even more advanced students at University level often do not use the pd. or voltage concept properly (Rhoneck and Volker 1985, Joshua and Dupin 1993). They think that "voltage is the strength of current". They also transfer the concept of "i=constant" to voltage by expressing the idea that "the voltage is the same" in a circuit. They are acquainted with i=constant and their description and explanation of current flow as an energy flow are compatible with the invariability of the electric current. Thus, for this purpose voltage is the second variable.

Similarly to the above mentioned, in the case of the Question 2.a and 2.b of the software (fig. 4-21) some students accepted the conservation of current on the condition that they introduced a second variable which described a property of the electric current and was related to their idea of voltage. Many students also reported that around the circuit the voltage stayed the same because they combine the invariability of current with the consumption of current.

In many textbooks voltage is described as the drive of electric current. This means that something is moving in the circuit, and this something does not move without the drive from a battery or another source. Besides this meaning the word drive has a considerable dynamic aspect. But voltage in physics is not force, it is potential difference.

The notion of stress may well be employed to underline the main features of the concept of voltage or pd. (Duit 1985).

Dupin and Joshua (1985) showed that reasoning with current is preponderant and voltage is rarely used. However, according to Maichle (1982) the notion that voltage can occur independently of the occurrence of current is very rare in elementary (20%) and secondary school students (30%).

There is a confusion between the current and voltage in complicated circuits, such as in the case of a circuit with parallel resistors (Millar and Beh 1993, Grob, Pollak and Rhoneck 1993). Thus, in this research many students thought that current instead of pd. was equal in each branch. The distinction between current and voltage could be made by a small number of students.

In Question 3.c - where there were two simple circuits, the first included one bulb and the second two bulbs connected in parallel, but all bulbs were identical - many students reported that current was equal in each branch, rather than pd. because "it has split into half and so it was smaller than in the first circuit". They did not take into account that the total resistance in the second circuit was reduced into half (local reasoning) (fig. 4-22).
Similar results are presented by Rhoneck (1982).

In Question 4, the three resistors were connected in parallel but in a complicated way (fig. 4-22). As before, 9 out of 30 students reported that current was equal in each branch of the first junction, instead of pd., because "it has split into half " and similarly in each branch of the second junction. Thus, they did not take into account that the total resistance in each branch of the first junction. This came from the fact that the total resistance in the one branch of the first junction was reduced into half.
Some students (3 out of 30) mentioned that the current had not split into half but paradoxically the greater part of it went through the greater resistance. Some others (2 out of 30 students) confused current and voltage in this parallel connection and so they reported that the current was the same in each branch, instead of pd., similarly to Unruh et al. (1997).

b) <u>Macroscopic representation of voltage and current</u>
The concept of voltage is the most difficult one within the physics curriculum at secondary school. "In contrast to current, which can be related to something which is moving, the physical background of voltage or pd. are electric fields where no mechanical analogies can be held... Students can hardly grasp the idea of voltage or pd. between two points when there is no visible or even thinkable (conceivable) difference between these points". Because of this difficulty, "all attempts which do not include an explicit and careful treatment of the field concept, ... can only explain the effects in parallel and series circuits on the basis of plausibility, such as if the pressure difference of parallel water pipes is the same then the voltage over two parallel resistors is the same" (Hartel 1985, p. 353).

Hartel's research (1985) proposed to change this attitude by teaching the subject in microscopic dimensions. This is another approach which introduces the concepts of electrical fields and surface charges. The absence of a microscopic link impedes students' ability to conceptualise the electric circuit as a system and to appreciate functional relationships between its parts (Ganiel and Eylon 1990, Hartel 1993).

In the above mentioned approach (Hartel 1985, p. 283) students measure the voltages across the battery, the wires, the switch, the bulbs and the resistors in a circuit. As a result of these measurements students can "find a rule on their own: A voltage is measured when a measurement device is connected with plus and minus". Taking into account the poles of a battery, students can say in another way that "a voltage is measured when a charge difference exists .... The battery constantly maintains a charge difference across its poles, no matter what current flows. The charge difference stands for the abstract pd. and causes the current in the circuit. It should be noted that charge difference is actually necessary in a circuit".
In this way, students can use simple operating rules when pd. or voltages are to be predicted, for instance, across two bulbs connected in series (as the sum) or in parallel (as the same voltage).

In his research with 13-18 year old students in Dutch secondary schools, Licht (1991b) proved that a microscopic representation (model) of voltage and current through a simulation programme has the potential to promote conceptual change with respect to all the alternative conceptions mentioned above.
Similarly, in their research with 14-16 year old students in Greek secondary schools Psillos and Koumaras (1993) claimed that "a computer-based learning environment could potentially provide students with unique opportunities to visualise and validate processes at a microscopic level".

As mentioned later in this chapter, microscopic representations (models) of current, such as the snapping marbles model in the stack "Current in wires" and a moving crowd analogy in the stack "Making current flow", were provided by the software and were very often used by most of the students in the research in an attempt to enhance their causal explanations of electrical interactions. So, in the post and delayed-post test phases they mainly identified the current flow as a transference of energy and as an event which is not stored.

It is common sense for teachers and educators that the concept of voltage remains vague; its formal definitions are not utilised operationally. Most students do not create a consistent picture of the developed mechanisms and therefore are unable to explain the phenomena. As mentioned in Chapter 1, some researchers (Ganiel and Eylon 1987, Metioui et al. 1996) claim this situation does not necessarily represent misconceptions but rather the lack of any clear concept.

c) Potential difference as an energy aspect

Voltage can also be described as the amount of energy given to a single electron per charge of electron (V=W/q). This energy is delivered to the electron in the battery and given to the lattice in the resistor. However, this results in difficulties with energy transfer especially in more complicated circuits and should be explained to students. This sort of definition should not be an introductory definition but should be taught to students once they have grasped the basic understanding and some experience of circuits, such as two resistors in series and two resistors in parallel -which has already mentioned in Millar and King (1993), Millar and Beh (1993) and Koumaras et. al (1986). In this way such a definition should come as a result of previous meaningful steps in the students' mind so that their reasoning is prepared.

Both Koumaras et. al (1986) and Eylon and Ganiel (1990) were aware of the presentation of the concept to students and proposed a certain teaching sequence for its introduction and development, as mentioned in Chapter 1.

In this research, four animated models (2 gravitational and 2 hydraulic) were presented to the students - several analogies to explain the same situation at the same time - for a coherent and complete mental picture of the concept.

Resistance and resistors

The concept of resistance is usually introduced as an electrical property of a certain component. The value of this property gives information about "how easily a current will pass through the component", as the students mentioned.

Many studies (Cohen et al. 1983 and Steinberg 1985) have shown students have difficulties with the concept of resistance. They regard a resistor as an "obstacle" to the flow of current and not as something which "draws" current. This view remains even after formal instruction at high school and among university level students (Steinberg 1985, p. 363-364), and even amongst physics teachers (Cohen et al. 1983).

Another way to approach this concept is to analyse a model of the atomic processes involved in electrical conduction.

Firstly, the approach introduced by Iona (1979) and later on other researchers such as Ganiel and Eylon (1987) & (1990), Psillos and Koumaras (1993) also supported it.

This approach is closer to the scientific model of the concept of resistance. Although it is attractive because it relates to the energy dissipation, it requires the students' readiness to learn about the underlying microscopic mechanisms of electric circuits.
As mentioned in Chapter 1, Johnstone and Mughol (1978) investigated a simple method for secondary school students (S2 to S5) to understand the concept of resistance. The researchers emphasised the relationship between resistance and the length and thickness of a conductor of uniform cross section. Their main recommendation is that the concept of conductance might be easier to teach than that of resistance.

According to the scientific model, resistance is due to the interaction between moving electrons and the ions of the conductor. Because of these internal electrical interactions, resistance is a concept which is described most clearly by using analogies. This process was used by many researchers (Hartel 1985, Koumaras 1989, Dupin and Joshua 1993) for better understanding of the concept.

In this research, the students showed a desire to study the provided models more, e.g. the hosepipe model for the concept of resistance and the anthropomorphic models in the form of a moving-crowd model (See later section). They repeated some of their explorations of these models. They also created similar analogies when explaining answers to questions from the software and the researcher [Gentner and Gentner (1983) p.p. 99-130].
Doubling the length of a wire, all else being equal (V, cross-section, material) leads to reducing current not because of "holding back" the current or producing greater "friction" in its flow and similar analogical representations, but simply because the field over the original length is halved. Although what has changed in fact is the field and an electrical analogue of pressure gradient has been provided by the software, asking students during post and delayed-post tests phases showed analogical reasoning was prevalent and dominating.
Thus, the influence of the software in both students' reasoning (the flow path aspect of resistance) and wording were shown as:
a) The wire of double length "doubly resists the flowing of the electricity just as a longer water pipe resists the flow of water";
b) "The longer wire more strongly resist the current" and "a smaller current flows through the bigger resistor";
c) "Resistance - in an analogical meaning frictional force - is doubled ... but then current has been halved, too".

Combinations of resistors (Questions 7, 8, 9 and 10)

Regarding a resistor as an "obstacle" to the flow of current, and not as something which "draws" current from the battery, works well for resistors in series but not in parallel. As mentioned Question 3 (fig. 4-22), for many students it came as a surprise that the addition of a resistor in parallel reduced the total resistance and remained a mathematical artefact. Similar findings were claimed by other researchers, such as Grob, Pollak and Rhoneck (1993), and Millar and Beh (1993).

In the designed software, Questions 1, 2, 3, 4, 5 and 6 are about simple connections of resistors :
a) in series (2 or 3 resistors and a bulb between them)
b) in parallel (2 or 3 resistors)
3) both in series and in parallel
Questions 7, 9 and 10 are about more sophisticated connections of 3 or 4 resistors and in Question 8 students needed to associate the microscopic (fields, electrons, forces between them) with the macroscopic parameters (current, resistance, voltage) of the circuit, as mentioned previously. Additionally, the Questions became progressively more difficult so as to provide a cognitive escalation for students' proper understanding of electric circuits.

With reference to Questions 7, 9 and 10 of the Software, in the students' mind the concept of resistors' connection in series became so closely associated with the image (aligned resistors) that there was no difference left between the concept and its pictorial representation. At this point, the canonical circuit drawings played the role of prototypes of series and parallel concepts. [Chi, Feltovich and Glaser (1981), and Seygmour (1979)].
A circuit picture more or less similar to a prototype influenced the students' answers when putting connected resistors into categories. They built mental representations of dc circuit problems from surface features which in this case are of a pictorial nature. The students probably stored in their memory concepts such as connection in series and in parallel as the prototypical image, instead of a list of their attributes based on physics principles underlying the properties of such circuits (Caillot 1985).
In Question 7, three resistors were short-circuited. In the Pre test, 30% of the students (9 out of 30) gave the correct answer and explanation while 50% of them (15 out of 30) ticked the formula Rtot = R1+R2+R3 because they explained that the resistors were connected in series. Furthermore, 4 out of 30 students considered that the resistors were connected in parallel and ticked

the relevant formula, but only 2 of them explained their answers. Also 2 out of 30 students gave no answer and no explanation.
Also in Question 9, three resistors were connected in parallel in a sophisticated way. 16 out of 30 students ticked the formula Rtot = R1+R2+R3 because they explained that the resistors were connected in series. 2 students gave no answer and no explanation. One student gave a wrong answer and a wrong explanation. Only one student gave the two correct answers and the correct explanation and the remaining 10 students gave incomplete answers and incomplete explanations.

Electric circuit as a system (Hartel)

According to research with students aged 16-17 years, Hartel (1985) suggested that one of the essential reasons that electrical concepts are so hard to understand and so difficult to teach, is that sequential reasoning is dominant and persistent, not only in secondary education but also in higher education. Textbooks and teachers of physics often support this kind of reasoning. The traditional teaching approach, in which every fundamental term (current, voltage, resistance) of a circuit is introduced in a linear sequence (i, q, V, R) according to the structure of the discipline, causes the above mentioned misconception.

For the first time Hartel (1982) introduced the three fundamental concepts (i, V and R) "simultaneously in a qualitative way, using the system aspect of electric circuit as an integrative base". He proposed that it is necessary:
1) To activate a new schema as a background for understanding these concepts by treating the system aspect in an explicit and clear way and appropriately using mechanical models, such as a water circuit, a bicycle chain, a stiff ring.
2) To discuss these models and compare with students' ideas which were influenced by local or sequential reasoning. This discussion acts as a support their understanding and change their way of thinking.
Moreover the treatment of the electric circuit as a complete system - similar to one of the models introduced - is adequate enough to explain and describe all the similar and different phenomena. In the process of teaching/learning this structure has to be developed further and in detail. Each of these models is a rather limited model and it acts as a frame for introducing and functioning the three fundamental concepts.

Similarly Hartel, Psillos et al. (1988) and Metioui et al. (1996) proposed that it is the variables voltage, current, resistance and stored energy which are necessary to study as a system.

Finally, Hartel (1993) concluded that the system approach with a computer-simulation modelling package helped to convince the students to change their own ideas and start their own thinking on these concepts. Similar remarks were also mentioned by Psillos and Koumaras (1993) from their research with secondary school students.

Ohm's law

As mentioned above, current is the students' primary concept because they regarded voltage or pd. as a consequence of current flow and not as a cause, as it is in reality. As a result of that, students often use V=i.R incorrectly (Cohen, Eylon and Ganiel 1983 p. 407).

As mentioned previously, in this research many students did not consider voltage to have the central role, and regarded current as "the prime concept", i.e. a simple battery is often considered as a current source rather than a voltage source. Moreover, pd. remained an abstract concept which students related by using V=R. i (Ohm's law). However, they could not realise that pd. can exist even between disconnected points of an electrical circuit.

The mechanism which relates pd. and current (or energy) is not clearly understood and the above mentioned relationship between them is basically mathematical. When a qualitative problem is presented, where some physical insight rather than arithmetic manipulations is necessary, then they face serious difficulties. Within this framework they adopted "local" reasoning because they did not realise that a change in one point of a circuit will cause changes in the whole circuit. A detailed discussion on the results from the Questions 1&6 and their Explanations is presented later on in this Chapter. Similar research findings are reported by Lightman and Sadler (1993), McDermott (1984, 1990, 1993) and Unruh et al. (1997).

The results clearly indicated that students focussed on current rather than pd. when studying electrical circuits.
One reason may be the fact that most students have studied electric circuits in some programmes, when they were young. These programmes had emphasised on current which is a more concrete and intuitive concept than

pd. Also they did not emphasise the importance of pd. as a cause of the flow of current which is in contrast to the emphasis of the software design.

Another reason may be the way the curriculum is taught at higher levels. It does not always clearly spell out the relation of cause and effect between pd. and current, as is the case in the software. A possible remedy is the introduction of semiquantitative models and analogies which explain the role of battery not only as an energy supply but also as "pushing" the charges with certain "pressure". This sort of example is presented in the "Making current flow", "Hydraulic 1&2", "Gravitational 1&2" and "Ohm's law" stacks, later on in this Chapter.

As mentioned in Chapter 1 and previously in this Chapter, diSessa (1983) also makes the point that many students are offered an explanation of Ohm's law in terms of phenomenological primitives (termed p-prims). Under these circumstances, Ohm's law is a case of a general law. It is a case of an impetus against the inertia to produce a result - the more you try to create an effect the more you will be resisted. Therefore, impetus is related to potential difference, inertia to resistance and the result is electric current. Nevertheless, in some studies (Jung 1985, Clement et al. 1987), in which this kind of analogy was used, misunderstanding arose.

As a result, many properties of resistive circuits can be analysed by another kind of analogy the fluid-flow analogy.
An incompressible fluid starts flowing almost instantaneously throughout the whole system as soon as a valve in the system is opened if pipes are already full of fluid. This illustrates the electrical case where the drift speed of the charges is very small, but the current flows throughout the circuit almost immediately after a switch is closed.
Also the moving-crowds analogy was applied. Instead of fluids, moving blocks were utilised.

Another recently developed way of approaching the concept of resistance is the analysis in terms of a model of the atomic processes involved in electrical conduction.
In the model (Iona 1979 mentioned previously), the term "obstacle" is used for resistance. This metaphor/analogy can explain the proportionality of resistance with factors, such as length, cross-section, composition of wires and temperature. It is also reported as "especially attractive" according to the students' comments and it was considered as a good approach of the concept of resistance because it also relates to energy dissipation.

For this reason the software provided various models, such as moving-crowd and anthropomorphic models which supported understanding of these concepts (see section on the useful models of electricity and on models and analogies in Chapter 1).

Language induced misconceptions

According to Sutton (1996) there is often a severe problem of lack of communication between teacher and pupils. When they communicate, what passes between them are the words and gestures they use to attempt to convey meaning, not meaning itself. So a teacher has some ideas which he/she hopes to convey by putting them into words, diagrams or symbols. The student may take note of the words, and so on, but from these has to build up a meaning for them. There is clearly a strong possibility that the meaning created by the student is not the meaning intended by the teacher. This possibility is very high if the type of language used by the teacher or the textbook writer is not familiar to the student. Then various things may happen, as Barnes (1976) has so clearly pointed out:
a) The student may ignore what the teacher is saying
b) The teacher may ignore what student is saying (the teacher "controls" knowledge by using unfamiliar language, consequently students' ideas are devalued and are only heard when they talk among themselves)
c) The teacher may insist that the students use the "correct" words and so, sound scientific (Osborne 1985).

Everyday language has considerable influence on people's views, on the way they think and consequently on understanding physical concepts such as the electric circuit (Logan 1981). According to Duit (1985, p. 205), the main sources of language induced learning difficulties are:
1) <u>"Language provides notions"</u>
Linguistic research of students' misconceptions have revealed many such examples in mechanics, astronomy, optics and heat. With reference to electricity no ancient notion seems to be conserved and so many notions of electric phenomena and processes are embedded in everyday language.
2) <u>"The logical structure of language leads and misleads thinking.</u>
The tendency in some languages to substantivate, e.g. to think within the thing category and to support a thinking in sequences of single cause-event elements has important impact on learning electricity". It is known from many studies (Hartel 1982, Closset 1985, Shipstone 1984, Heller and Finley 1992, Koumaras et al. 1997) that "students concentrate on local processes and

prefer sequential reasoning. They have severe difficulties in taking all parts of a circuit into consideration and are almost unable to think of the circuit in terms of a system. The inability to think in interaction rather than in single cause-event-elements which hampers human understanding in many complex fields originates from the structure of language" (Duit 1985, p. 207).

3)" Concept names are also used in everyday language

Concept names in physics are borrowed from everyday language,... motivated by the intention to point out some basic features of the concept via the concept name... The motivation originates in fluid models of electricity developed in 18th century" (Duit 1985, p. 207). However, these words often do not lead to main aspects of the concept and a result of that is the existence of learning difficulties and misconceptions. It is interesting that language-induced learning difficulties have been observed in many languages (German, Swedish, English, Greek).

Thus, as Shipstone (1984) and Sutton (1996) mentioned, sequential reasoning by students about the current flow is supported by teachers and textbooks because of the language used in physics instruction.

Often physics concepts belong to different categories from those of the respective common sense concept. In his research Jung (1985, p. 198-199) used Category - Questionnaires for students at the end of secondary school (8 graders = 70, 10 graders = 73) to subsume an electric concept under a very general category. The concept-words were: electric current, voltage, electric charge, electron and energy. The categories were: event, substance, property and no answer.

Results of this research showed that :

Current

The majority of students considered current as a substance but a high percentage (25-30%) also considered it as an event. From a sample of University students (trainee teachers) similar results were also given by Maichle (1982).

Voltage

49% of 8th graders considered voltage as a substance but a high percentage (26%) also considered it as an event. 40% of 10th graders considered voltage as a property but a high percentage (32%) also considered it as an substance.

Charge

47% of 8th graders gave no answer. However, a high percentage (30%) considered it as an event. 51% of 10th graders considered as a property. However, the rest of them were divided, considering charge either as a substance (22%) or as an event (18%).

Energy

8th graders considered energy either as an event (30%) or as a substance (30%) or as a property (37%). A high percentage of 10th graders considered energy as a substance (38%) or as a property (37%). However, 21% of them also considered it as an event.

Electron

8th graders did not answer. The majority of 10th graders (95%) considered electron as a substance. In addition, comparing:

Current and energy

There is a very significant difference between the categorisation distributions of the two concepts. Energy is categorised equally often as "substance" and as "property" but current is not.

Current and voltage

There is a very significant difference between the categorisation distributions of the two concepts. Voltage is categorised often as "property" but not so current.

Current and charge

There is a significant difference between the categorisation distributions of the two concepts. There is a conversion of the substance and property categorisations.

Voltage and energy

There is no significant difference between the categorisation distributions of the two concepts. There is a small bias in favour of "property" for voltage compared to energy.

It is worth noting that results with a Category-Questionnaire asking for the best analogy for current showed that the majority of students (81% of 8th graders and 90% of 10th graders) chose an occurrence (rain, stream of air, river, stream of sand) as best one, and both samples had a peak with river. 10th graders thought current in terms of "moving electrons", but the predominant aspect was not movement but the substantial things which moved (can be at rest, can be stored etc.). Thus, current is different from energy. Voltage is considered similarly as current by 8th graders but not by 10th graders.

Finally, the multiple meaning of these concepts' words limit the opportunities for physics teachers to create a consistent image of the processes in circuits in students' minds. For such confusion to be avoided attention must be paid to the proper use of language (correctness of the used electric terms).

This particular software design focused both on students' preconceptions and on their reasoning. As pointed out by Sutton (1996) and Koumaras et al. (1997), also a wider strategy, aiming at facilitating students' understanding of electric circuits, was used so that a basis for communicating such concepts could be established, and which used persuasive language for teaching.

4.3.5 SOFTWARE DESIGN STRATEGIES TO AVOID MISCONCEPTIONS

The appropriate strategies when learning a physical concept are:
1) "Fixing the right category but avoiding too specific a meaning.
It (the category) is generated as something of a certain type assumed from observable circumstances, whose further properties and relations have to be explored" (Jung 1985, p. 238).
2) Introducing an energy perspective of the electric circuit.

* The electric circuit may be explained as a system (Hartel 1985) where energy is transformed or as a system where voltage is measured and current flows.

* In the electric circuit, the concepts of potential difference or voltage, current and resistance are combined (Steinberg 1985).

Both views are connected. As mentioned above, "the energy flow dE/dt into a resistor is given by the product V. i, which means that voltage and current determine the energy flow. The flow of electrons and the energy flow should be distinguished very carefully. The first circulates and the second is undirectional" (Rhoneck and Volker 1985, p. 96).

4.3.6 USEFUL MODELS OF ELECTRIC CIRCUITS, CURRENT, VOLTAGE AND RESISTORS

Models

Interacting with the environment and especially with the technical equipment, people form internal, mental models of them. These models provide predictive and explanatory power for understanding the interaction. With reference to these models four elements can be considered:
a) the target system or new, unfamiliar knowledge;
b) the conceptual model of the target system or familiar knowledge/analogy;
c) the learner's mental model of the target system;
d) the scientific conceptualisation of that mental model;

The system that the student is learning is the target system.
A conceptual model is invented to provide an appropriate representation of the target system. Conceptual models are invented by teachers and scientists, and are devised as tools for the teaching & learning of physical systems.

Mental models are naturally evolving models. Through interaction with the target system, people formulate its mental models. These are the models that people actually form in their mind which in turn guide them in using the technical equipment. These models are not usually accurate, but they must be functional. Interacting with the target system people continue to modify their own mental model in order to get to a workable result (Karrqvist 1985, p.p. 215-226). Mental models are both constricted and driven by the learner's background, previous limited experience with similar systems and the structure of human memory. Obviously, the scientific conceptualisation of a mental model is a complete and integrated model.

Human mental models may be deficient because of the inclusion of contradictory, erroneous and unnecessary concepts. So, designers need to evolve instructional material enabling the students' development of more coherent, usable mental models. Teachers need to develop conceptual models with which students can evolve adequate and appropriate mental models.

Mental models used in electricity

Research findings concerning the analogical instruction and the use of models and analogies for learning various subjects and electricity were discussed in Chapter 1. Chapter 2 contains detailed discussion of how metaphors (using the word in its widest sense) work to facilitate the acquisition of the new knowledge (store and retrieval) according to the Information Processing Theory of Learning, Ausubel's Viewpoint of Learning and the Psychological Processes in the Comprehension of Metaphors.
The model of current which is universally accepted is one of moving electrons in a wire, responding to a potential difference (pd.) across the ends of the wire. This model generally requires students to have basic knowledge of atomic structure. The mental images associated with this model are reinforced by common analogies and/or models used by many teachers and textbooks.

Emphasis is given to the models most frequently used because they have become accepted as useful in learning & teaching electrical concepts by students, educators and researchers, as mentioned below.

a) Two analogies for electricity

Analogical comparison of simple and familiar systems occurs when people describe complex systems, both as explicit models and implicit analogies in which people borrow language from one domain as a convenient way of talking about the other one. Both models and analogies are more than the vocabulary with which people discuss the results of independent inferential processes.

Mechanisms of electricity are essentially invisible. Therefore it is explained by analogies and models. Moreover, no single analogy has all the correct properties; different analogies are used for the same target domain. Finally, an advantage in electronics, is that by using simple combinations of circuit elements, it becomes easy to devise a problem which requires quantitative inferences, which cannot be mimicked by mere lexical connections.

Flowing - fluid or Water - flow analogy

In literature, the water-flow analogy is most frequently used in electricity. The analogy is meant to convey a system of relationships which can be transmitted from hydraulics to electricity. As in literature also in this software, the base domain is a plumbing system, the water pipe corresponds to a wire, a pump/reservoir corresponds to a battery/source of pd., a narrow constriction corresponds to a resistor and flowing water corresponds to electric current.

The pressure of the water at the outlet of the reservoir is proportional to the height of water in the reservoir. Pressure is the force of water per unit area. The rate of flow is how much water is flowing per unit time. Pressure and flow rate are clearly distinguishable. There is a relationship between them: the rate of flow across a section is proportional to the pressure difference through that section. Therefore the greater the height of water in the reservoir the greater the flow rate, all else being equal.

A constriction in the pipe results in a drop of pressure and also affects the flow rate. Water pressure, which is high when the water leaves the reservoir, drops across the constriction. Therefore, the greater constriction in a section, the smaller flow rate through that system.

The plumbing system is an analogy of an electric circuit. The attributes shared are relational attributes, i. e., the greater the height of water in the reservoir the greater the flow rate, otherwise increasing pd. results on increasing current.

The distinction between the concept of current and the concept of pd. is the first insight come from the analogy. This aspect of the analogy is important because some students often can not differentiate between current and pd. merging both of them into a kind of generalised-strength notion.

In addition to the current - pd. distinction, the analogy conveys the interrelation between current, pd. and resistance. Batteries, wire and resistors of an electric circuit are analogous to reservoirs, pipes, and constriction of a plumbing system. Electrons flow through the circuit because of pd. produced by the battery, just as water flows through the plumbing system because of a pressure difference produced by the reservoir. Also the second insight come from the analogy is the dependency relations which constitute Ohm's law.

<u>Moving - crowd analogy</u>

In addition to the hydraulics model, the most frequent spontaneous model is the moving-crowd model, which provides most of the relationships required to understand electric circuits. In this model:

electric current is seen as many objects racing through passageways;

electric current corresponds to the number of entities which pass a point per unit time.

Voltage or pd. corresponds to how powerfully these objects/entities push. The moving-crowd model establishes a distinction between current and pd. or voltage.

Furthermore this model allows a superior treatment of resistors. In this model a resistor corresponds to a barrier containing a narrow gate. The "gate" conception of resistors is helpful in predicting how combinations of resistors behave. However, it is not useful in predicting how combinations of batteries behave.

In this software, the "snapping marble" model is used to introduce the concept of electric current. Marbles are seen as (free) electrons in a wire and movement of marbles is seen as electric current.

The "electrical pressure" at the first marble of the row is proportional to the speed of a marble which strikes the first marble. The rate of flow through any point in the system is the number of marbles passing that point per unit time. "Electrical pressure" and flow rate are clearly distinguishable: rate of flow is how many marbles are moving while "electrical pressure" is the energy per marble. There is a relationship between "electrical pressure" and flow: the rate of flow through a section is proportional to the "electrical pressure" difference through that section. Therefore, the higher the speed of a marble the greater the flow rate, all else being equal. Thinking analogically, increasing pd. or voltage causes an increase in current. An insight derivable from the model is the distinction between the concept of current and of pd. or voltage.

b) Anthropomorphism

According to Solomon (1986), Osborne & Freeman (1989), Sutton (1996), Stocklmayer &Treagust (1996) and Taber & Watts (1996) anthropomorphism is helpful in teaching students and is used frequently, in different ways in our culture. It is a kind of analogical reasoning. Consequently, it is a precious tool for expanding human knowledge (Dupin and Joshua 1989, Duit 1991). It is argued that anthropomorphic language is common amongst scientists as well as students. It is also a point of interest that some of Robert Boyle's images are mildly anthropomorphic, as he plays with the idea of particles "brandishing", and "whirling" with an expansive "endeavour".

Working from a constructivist perspective not only Watts and Bentley (1994) but also Taber and Watts (1996) have argued "in favour of humanising school science deliberately reviving/allowing anthropomorphic and animistic thought". Both of them have also have discussed the merits of anthropomorphic and animistic language in teaching & learning science. Scientists derive their new ways of talking about a topic by drawing upon their imagery, as well.

Anthropomorphism is used often by physics-naive people as a primitive explanation. However, even experts invent more of them for pedagogical reasons. Electrical engineers and physics teachers often speak of a resistor as a kind of transformer which converts current flow into voltage "... a current i causes a potential drop iR when flowing through a resistance R ...". When the students were asked to insert the values of the pd. across certain points of a circuit they gave their explanations to Question 2 of the software with similar metaphorical interpretation (fig. 4-21).

Anthropomorphism usually is introduced by an analogy which is based on developing animated attributes of the target and ideas on its behaviour. These ideas permeate discussions on the explanations of students'

observations. They are "explaining a physical phenomenon on the basis of human being behaviour". Learners build a set of activities out of some already existing set from their experience on human activities. According to Fisher (1987) this learning state is called the personal analogy where students place themselves directly in the same situation with the target.
In his article "Evolution of intuition" A. diSessa (1983) mentioned that "anthropomorphism is frequently offered by learners and is forced as a rationalisation for what they remember".

In his article "Students' understanding of electricity in five European countries" Shipstone (1988) illustrated, with a cartoon, the fact that there is an almost 'natural' coherence to the learning difficulties within a cognitive structure, such as consumption of current, constant current from a battery, defective differentiation between current and voltage, local and sequential reasoning.
In his book "Investigating Electricity", a simple anthropomorphic model is provided by Peter Warren (1983) in the delightful cartoons used. Not only are these clear and amusing, but they also provide concrete visual models of many simple electrical phenomena. In addition, they clearly show that the carriers of charge are not 'used up' as they pass through resistors and bulbs, for example in the cartoons about electrical conduction, resistors in series and in parallel etc.

As mentioned, the domain of simple electricity is ideal for using analogies in teaching & learning because its mechanisms are essentially invisible. The use of models has also been proved as a powerful tool for teaching & learning Science by many researchers (Bauman 1980, Gentner and Gentner 1983, Black and Solomon 1987, Duit 1991).

Moreover, according to Gentner D. and Gentner D. R. (1983) and other researchers' findings, different analogies can be used for the same target domain because no simple analogy has all the correct properties. So, Gentner D. and Gentner D. R. (1983) find the fluid-flow analogy better explains connections in series and in parallel for batteries than for resistors while the moving-crowd analogy better explains the connections for resistors than for batteries.

4. 3. 7 SOFTWARE DESIGN BASED ON STRATEGIES TO AVOID MISCONCEPTIONS

a) Current

In the "Current in wires" stack, the first card is the picture of "Marathon fever - A current of people on move" (anthropomorphic model) which is an analogy of the electrons' drift. Then, an animation of one (or more) snapping marble(s) against the one end of a row of marbles follows, as mentioned above.

With reference to the first strategy to avoid misconceptions, the picture of "Marathon fever - A current of people on move" is the starting move of the "generative path" for students to fix the right category. Jung (1985) proposes that the meaning of electron drift as an introduction to the concept of electric current which has advantages such as:

a) Students learn that current is not a substance but an event (or occurrence) at every point in a circuit;

b) Illustrating that an event is not stored or is not used up;

c) By fixing the meaning of current as event at a point in a circuit students avoid associations of movement in one or other direction;

d) Students stress what in fact can be observed, orientation in the mathematical sense, instead of stressing direction of movement and/or transportation.

Finally, as Jung (1985) claimed "Though it may seem paradoxical at first sight, fixing meaning and reference as some local occurrence does foster global, or better functional, reasoning" (p. 239).

With reference to the second strategy to avoid misconceptions, the animation of the snapping marbles is a moving - crowd model which identifies the current as a flow or transference of energy from the first to the final marble of the row and additionally has the above mentioned advantages. Through interaction with the buttons, reducing and/or increasing the speed and the number of the marbles, students realise that electrons do not come pouring out of the end of the wire like water from a pipe; instead they send energy along the wire quickly and with relatively little motion of individual electrons.

Later on, in the "More about the electric current" stack, there is an anthropomorphic model which should introduce the electric current in the microscopic level of free electrons in the case of a metallic conductor or just electrons in general. The model consists of animated pictures illustrating the (free) electrons while passing through a cross-section of a conductor. It is of fundamental importance for the following concept of intensity.

In the "Making current flow" stack, there is a moving - crowd analogy which emphasises:
1) The energy role of the battery (or pd. or electro-motive force) in a circuit. It does not create an electric charge but it gives a certain amount of energy to each Coulomb.
2) The correlation between pd. and current, that means current is the result of pd. which pre-exists in a circuit.
3) The current flow as an energy flow in a circuit.
4) The direction of current.

In the "Which ways is the current flowing" stack, both real and conventional currents are presented and illustrated as moving - crowd models. Now, the direction of current is presented in detail. Basically, it is of fundamental importance for establishing current flow as an energy flow, by using the following strategy.
Firstly, students are informed how to calculate the average speed of the (free) electrons in a copper wire with certain features.
Secondly they are asked to calculate the time that a bulb takes to light, if the bulb is connected to a switch with a similar wire of certain length. So, for a 20 m length of cooper wire the required time is 135,135 secs. This is in contradiction with their experience, because if they turn on the switch, the bulb lights immediately. Also, they mention that it looks like snapping marbles. "Because electric current (some students mention electricity) is transference of energy from the first to the last electron of the row of the copper wire, energy is transferred immediately and the bulb is on at the same time".

b) Intensity (or size)
Naturally, the concept (meaning) of intensity (or size) arises when making the comparison between what happens in one place and another. In the "Intensity of electric current" stack, there is also a moving - crowd model. Actually, it is an analogy (or a metaphor) between one Coulomb of charge and one small wagon of a train. Clicking on the finger button causes a simulation of the wagon's movement to be shown on the screen, while the man counts the number of wagons per sec passing under him. Thinking analogically, that means the number of Coulombs per second or the number of Amperes.

In the "Current at a junction" stack, there is an animation of a picture presenting an analogy of a current at the junction of two resistors (anthropomorphic model).

An observer counts the number of runners before and after the junction and mentions that both are equal. Thus, the conclusion is presented by a text-field in which there is emphasis on the conservation of current. It is mentioned that "at every junction in a circuit the total current which flows in equals the total current which flows out. No current can be 'lost' (in other words 'used up') at a junction nor can more current leave than enter".

Additionally, the influence of resistors on the current is mentioned in text-field "Most of us go the easy way" which represents the runners' thought before entering the junction. It is worthwhile to mention that fewer runners go through the larger resistor and more through the smaller resistor. There is further information on how the current is divided according to resistance of each path not only for the above mentioned picture and but also for three other animated examples. In the examples, emphasis is given to the fact that 'current x resistance is the same for each resistor since the pd. is the same across each branch' (ratio rule).

Finally, it is of fundamental importance that the system aspect of the electric circuit as an integrative base is used because the three fundamental terms - current, voltage, resistance - are simultaneously presented in a qualitative way.

c) Potential difference - Voltage

In the "Potential difference" stack, the first card is a picture - acting as a metaphor at the same time - in which every wagon represents one coulomb charge. With reference to the first strategy to avoid misconceptions the potential difference at the terminals A, B expresses the energy per unit charge which is transferred along the line part AB.

Recent research on learning about electrical circuits (Hartel 1993, Psillos and Koumaras 1993) claims that one source of confusion is the use of the terms potential, pd., voltage and e.m.f.

To reduce this confusion, a pop-up-field helps students to distinguish the meaning of the three first terms. With reference to the second strategy to avoid misconceptions and introducing potential in a microscopic level, they consider electrons going round a circuit so they lose electrical potential (development of functional relationship between voltage and current and notion of current as a consequence of pd. in a circuit). The pop-up-field indicates pd. as "the potential drops". Thus, the potential difference across a component is just the difference of potential between electrons entering and leaving a component. The pd. is measured in volts (=the number of joules for each coulomb of charge) and it is often referred to as the voltage across a component.

Being referred to the "Making current flow" stack, the pd. developed across a battery (or cell) is called electromotive force (e.m.f.) and often misnamed voltage, as some students indicate. Thus, some of them claim that "It is better to avoid the term voltage and to use potential difference or electromotive force explicitly". The "Qualities" button also acts as reminder of basic information on pd. such as:

1) The potential difference across the terminals of a set of conductors in series, is equal to the sum of the potential differences across everyone of them (Kirchhoff's path rule).

2) Both conductors (bulbs) are connected in parallel, having two common points and the same potential difference.

Navigating the "Voltage dividers" stack, in the first card current, voltage and resistance are closely related in the circuit (development of functional relationship between voltage or pd. and resistance). In the second card, on the positive path from the battery, the voltage equals the battery's, but after passing through a component, it drops to 0V on the negative path.

However, when several components are connected in series, the drop to 0V takes place over all the components. The voltage across each depends on its resistance. The components share the battery voltage, and together they are called a voltage divider. In the third card, there is a simple arithmetic manipulation in which the students can calculate how much voltage is dropped by each component using Ohm's law.

A functional relationship is proposed by a simulation of a voltage divider in which the animals are like components, using the smaller amount of water for their own needs. The locks are like a voltage divider, and the water-wheel is like a battery. Whereas, for example, the cow needs a lot of water, the hen only needs little. The water's force is slightly less at each lock gate, but then it flows back to the water-wheel which sends it back round the circuit with the same force as before. As a result of that, the students are stimulated to create relationship between pd. or voltage across each resistor and the size of a resistor and not to miss the conservation of current in a closed circuit.

According to Gutwill et al. (1996) and Stocklmayer & Treagust (1996) it is important to present the concept of potential difference through different models. Thus :

As mentioned previously (Flowing-fluid or Water-flow analogy, p. 219) in the "Hydraulic 1" model, the hydrostatic pressure at any point in the water circuit is analogous to the electrical potential at that point. The (more familiar) concept of pressure is measured by a manometer connected between these two points. The pump or reservoir raises the water to a higher pressure (gives water higher potential). The water flows round the circuit unimpeded, until it reaches the constriction, in which the pressure falls (there is a potential drop). There can be a potential difference between two places even though no current is flowing; this is the normal condition between two terminals of a disconnected battery. The equivalent for a water circuit is a dam holding back water (electric field - electrical analogue of pressure gradient).
In the "Hydraulic 2" model, there is an animated picture which emphasises pd. or battery and their energy role in a circuit as a transformer of energy. The picture is an analogy of the whole process of this event. The students are stimulated to think in a metaphorical way and they claim that "pd. gives to every unit of charge energy and that's the flow of current inside a conductor" (microscopic level of reasoning). At the same time a reminder for the direction of dc. current is presented because it flows constantly in one direction (see previously in the "Current" section).

In the "Gravitational 1" model, the height analogy for potential is useful and easy to put across. Simply stated, gravitational potential energy can be used as an analogue for electrical potential energy. In this model a cell or battery lifts electrons to a height governed by e.m.f. of the cell. The electrons then fall back downhill and give up energy as they pass through resistors on their way back to the cell.

In the "Gravitational 2" model, more emphasis is given on the pd. or battery's energy role in a circuit. In this case, the pd. or battery in a circuit looks like a machine which raises water from points of lower to points of higher potential. A pop-up-field indicates that the pd. is neither a source of electric charge nor a creator of energy; it is simply a transformer of energy.

d) Resistance - Resistor

After current and voltage, resistance is introduced as the third main ingredient of a circuit.
With reference to the first strategy to avoid misconceptions in the "Resistance" stack, an animated picture of a hosepipe presents the concept in the frame of analogical reasoning so that resistance is the way certain substances oppose the flow of electrons and so reduce the size of current.

With reference to the second strategy firstly emphasis is given to its role in controlling the current and the voltage for another component in a voltage divider, as mentioned previously in the section of pd.

Later on, in the "Ohm's law" stack, students explore whether all resistors follow this law through diagrams of i=f(V) in the case of a copper wire, a bulb and diodes. Because Ohm's law is of great importance, an animated picture presents the formula as a triangle in which if a student puts his/her finger over the quantity he/she wants it is easy to see how the formula works.

So, in the post and delayed-post tests students claim that it (resistance) indicates "the ease/difficulty of the pathway of the electrical flow and, by implications, affects the value of current in a circuit". They clarify that all components resist current to some degree, but some components -which are called resistors- are specially made "to cut down the current".

In the "R=pl/s" stack, the dependence of resistance on the length, thickness and material of a conductor is presented in a microscopic level. The concept of resistivity and its categorisation as insulators, semiconductors and conductors is introduced by animated cartoons (anthropomorphic models). A range of resistivities between the best conductor and the best insulator is provided so that students indicate that good conductors of electricity "allow electrons to flow easily". Sometimes, though, "they bump into atoms in the wire and this slows them down". This braking effect is called the wire's resistance. "The longer the piece of wire, the more resistance it has".
In this viewpoint, thick wire has lower resistance than a thin wire because they claim that "there is a larger area of wire for the electrons to pass along. It is a bit like a motorway which can carry more traffic than a single-lane country road". Similarly, they mentioned that "difficulties increase for the current as the wire gets longer, so not much current can pass through" and " a smaller current flows through the bigger resistor". As a result of that, electric current passes very easily through the really good conductors and the lamp shines with full brightness.
Some materials do conduct electricity, but the electric current has some difficulty in getting through. These are considered as semiconductors. Additionally, in some materials the electric current has very great difficulty in getting through. These are categorised as insulators.

In the "R=R(θ)" stack, resistance depends on the temperature of a conductor and students explain this fact as "because of the frictions, as the flowing particles pass through a resistor, an increase in its temperature has as a result greater number of frictions and so greater resistance ".

Adding resistors, the anthropomorphic models provided - in the form of moving-crowd models - clearly present that the carriers of charge are not "used up" as they pass through resistors.

Finally, in all above mentioned cases, one of the aims of the software was the change in the function of the bulb from a consumer to a resistor, acting as an obstacle in the current flow. This change prompts students to use some kind of mechanism to explain how this is done. This accounts for "move-crowd electrons" arguments which present a shift from the use of macroscopic quantities to microscopic entities which contribute to the students' readiness to learn about an underlying microscopic mechanism for electric circuits.

4. 3. 8 CONCLUSIONS ON THE FRAMEWORK OF THE SOFTWARE DESIGN BASED ON STUDENTS' MISCONCEPTIONS

Firstly, in this research, learning electricity focused on the development of students' ability to separate their ideas on current from the notion of energy (Shipstone and Gunstone 1985) and to emphasise an independent concept of potential difference (Rhoneck and Volker 1985, Metioui et al. 1996, Stocklmayer and Treagust 1996). The software highlights the role of current as a transporter of electrical energy so that the students consider a current flow as an energy flow through a circuit's components.

Secondly, another central point of this research is concerned with the following feature of an electric circuit: when a modification is introduced in a certain part of the circuit, there is a "global" change in the circuit (Cohen et al 1983). Thus, the students are able to consider both global and local changes and not to stick to a local analysis in a circuit, as usually happens.

Thirdly, the use of qualitative questions - provided by the Software Part 2 in combination with the Software Part 1 (Theoretical feedback) - forces the students, not only to apply mathematical manipulations automatically and in a mechanical way, but also to consider the functional relationships between variables which characterise electric circuits. Consequently, the students can reason qualitatively in the context of the subject domain (Cohen et al 1983).

Finally, according to Rhoneck and Volker (1985, p. 95) students' descriptions of the processes in a circuit are related to the energy view. "The electric circuit may be explained as a system where energy is transformed or as a system where voltage is measured and current flows. In the energy view, the battery is the place where energy is stored and it is transformed from chemical to electrical energy. From the battery, the energy flows to the electrical appliance". This is another way of looking at an electric circuit in which the concepts of pd. or voltage, current and resistance are used simultaneously and in a qualitative way (Hartel 1982 & 1993).

As mentioned previously in this Chapter, both views are connected to each other in such a way as: the energy flow dE/dt into a resistor is provided by the product i . V. Consequently, current and voltage determines on the energy flow. Students must carefully differentiate between the energy flow and the electrons flow.

4. 3. 9 ANALYSES OF THE RESULTS FROM QUESTIONS 1&6 AND THEIR EXPLANATIONS

Question 1 and Explanation 1

The aim and objective of Question 1 were to diagnose students' misconceptions related to the location of a bulb in a series circuit.
From the results of their answers to the Question 1 and their Explanations, for the brightness of a bulb 11 out of 30 students did not take into account the total resistance Rtot, but did take into account the location of a bulb between the resistors of the circuit (sequential reasoning). This sort of misconceptions was revealed by Questions 1.b and 1.d in particular.

In the Post and Delayed-post tests :

* instead of their own some students used expressions and words provided by the software. The use of the term "Influence" means the change in students' wording.

* all students answered correctly and gave correct and complete explanations to their answer.

Students gained benefit from the software particularly in explaining correctly and completely their answers to the question.

Question 1.a and Explanation 1.a (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 1.a			
(Increase) C	29	30	30
(Decrease) W	1		
(Stay the same) W			
Explanation 1.a			
CR	23	30	30
CR ?	4		
NoR	2		
W R	1		
Influence		8	8 (1H+4M+3L)
C and CR ?	4 (3L+1H)		
C and NoR	1 (1L)		
C and WR	1 (1L)		
W(decrease) and NoR	1 (1L)		

Pre Test

29 out of 30 students answered to the Question 1.a correctly.

> 23 out of 29 gave correct and complete explanations to their answer.
> 4 out of 29 gave correct but incomplete explanations to their answer.
> 2 out of 29 might gave correct answer by chance because one of them gave no explanation and the other gave a wrong explanation.

Post and Delayed-post Tests

Students gained benefit from the software, indicated by them being able to explain correctly and completely their answers to the question.

With reference to :

a) The level of background knowledge of physics, students of low level benefited more (7 students = 6L+1H).

b) The influence from the software, students of low and middle level benefited more (8 students = 1H+4M+3L).

Question 1.b and Explanation 1.b (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 1.b			
(Increase) W	2		
(Decrease) C	17	30	30
(Stay the same) W	11		
Explanation 1.b			
CR	15	30	30
CR ?	1		
NoR	3		
W R	11		
Influence		8	8 (1H+4M+3L)
C and CR ?		1 (1H)	
C and NoR		1 (1M)	
W(increase) and NoR		2 (2L)	
W(stay the same) and WR		11 (3M+8L)	

Pre Test

17 out of 30 students answered correctly to the Question 1.b.

15 out of 17 gave correct and complete explanations to their answer.

1 out of 17 gave correct but incomplete explanations to their answer.

1 out of 17 might have given the correct answer by chance because s/he gave no explanation.

13 out of 30 students gave a wrong answer.

2 of them answered that the brightness of the bulb increased but they did not give any explanation.

11 of them answered "stay the same" because of the location of the bulb in the circuit. They meant that the resistor is after the bulb and any change does not influence on the bulb's brightness.

Post and Delayed-post Tests

With reference to :

a) The level of background in physics, students from a low level benefited more (15 students = 10L+4M+1H).

b) The influence from the software, students from a low and middle level benefited more (8 students = 1H+4M+3L).

Question 1.c and Explanation 1.c (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 1.c			
(Decrease) C	29	30	30
(Increase) W	1		
(Stay the same) W			
Explanation 1.c			
CR	22	30	30
CR ?	2		
NoR	4		
W R	2		
Influence		8	8 (1H+4M+3L)
C and CR ?	2 (1L+1H)		
C and NoR	3 (3L)		
C and WR	2 (2L)		
W(increase) and NoR	1 (1L)		

Pre Test

29 out of 30 students correctly answered to Question 1.c.

22 out of 29 gave correct and complete explanations to their answer.

2 out of 29 gave correct but incomplete explanations to their answer.

5 out of 29 might have given correct answer by chance because 3 of them gave no explanation and 2 of them gave a wrong explanation.

Post and Delayed-post Tests

With reference to :

a) The level of background in physics, students from a low level benefited more (8 students = 7L+1H).

b) The influence from the software, students from a low and middle level benefited more (8 students = 1H+4M+3L).

Question 1.d and Explanation 1.d (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 1.d			
(Increase) W	1		
(Decrease) C	18	30	30
(Stay the same) W	11		
Explanation 1.d			
CR	16	30	30
CR ?	1		
NoR	2		
W R	11		
Influence		8	8 (1H+4M+3L)
C and CR ?	1 (1H)		
C and NoR	1 (1L)		
W(increase) and NoR	1 (1L)		
W(stay same) and WR	11 (3M+8L)		

Pre Test

18 out of 30 students correctly answered to the Question 1.d.

16 out of 18 gave correct and complete explanations to their answer.

1 out of 18 gave correct but incomplete explanations to their answer.

1 out of 18 might have given the correct answer by chance because s/he gave no explanation.

12 out of 30 students gave the wrong answer.

1 of them answered that the brightness of the bulb decreased but did not give any explanation.

11 of them answered "stay the same" because of the location of the bulb in the circuit. They meant that the resistor is after the bulb and any change does not influence on the bulb's brightness.

Post and Delayed-post Tests

With reference to :

a) The level of background in physics, students from a low level benefited more (14 students=10 L+3M+1H).

b) The influence from the software, students from a low and a middle level benefited more (8 students = 1H+4M+3L).

Question 6.a and Explanation 6.a (Table 4-1)

	Number of students		
	Pre	Post	Dell
Question 6.a			
(b, c) W	6		
(c) C	23	30	
(I don't know) No	1		
Explanation 6.a			
RC	17	30	
RC ?	1		
nor	1		
W R	11		
Influence		11	11 (1H+5M+5L)
C and CR ?	1 (1M)		
C and WR			
(location of bulb+Rtot)	5 (4L+1M)		
W and WR			
(location of bulb)	6 (1M+5L)		
No and NoR	1 (1L)		

Pre Test

23 out of 30 students answered Question 6.a correctly.

17 out of 23 gave correct and complete explanations to their answer.

1 out of 23 gave correct but incomplete explanation to their answer.

5 out of 23 might have given the correct answer by chance because they gave wrong explanations.

6 out of 30 students gave a wrong answer because of the location of the bulb in the circuit with reference to the other resistors (the bulbs in the circuits "b" and "c" are brightest because in both cases "the bulb is after the first resistor"). 5 out of 30 students gave a correct answer but wrong explanation (the bulb in circuit "c" is brightest because "the bulb is after the first resistor and Rtot is less than in circuit "b" ").

Post and Delayed-Post Tests

With reference to :

a) The level of background in physics, students from a low level benefited more (13 students=10L+3M).

b) The influence from the software, students from a low and a middle level benefited more (11 students = 1H+5M+5L).

Question 6.b and Explanation 6.b (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 6.b			
(c) W	11		
(a,b,c) C	18	30	30
(I don't know) No	1		
Explanation 6.b			
CR	17	30	30
CR ?	1		
NoR	1		
W R	11		
Influence		11	11 (1H+5M+5L)
C and CR ?	1 (1M)		
W and WR (location of bulb+Rtot)	5 (4L+1M)		
W and WR (location of bulb)	6 (1M+5L)		
No and NoR	1 (1L)		

Pre Test

18 out of 30 students answered Question 6.b correctly.

17 out of 18 gave correct and complete explanations to their answer.

1 out of 18 gave correct but incomplete explanation to their answer.

None of them could have given a correct answer by chance.

6 out of 30 students gave a wrong answer because of the location of the bulb in the circuit with reference to the other resistors (the bulb in circuit "c" is brightest because "bulb is before the first resistor").

5 out of 30 students also gave a wrong answer (the bulb in circuit "c" is brightest because "bulb is before the first resistor and Rtot is the same in all circuits ").

Post and Delayed-post Tests

With reference to :

a) The level of background in physics, students from low level benefited more (13 students=10L+3M).

b) The influence from the software, students from a low and a middle level benefited more (11 students = 1H+5M+5L).

Question 6.c and Explanation 6.c (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 6.c			
(a,b) W	11		
(c) C	18	30	30
(I don't know) No	1		
Explanation 6.c			
CR	17	30	30
CR ?	1		
NoR	1		
W R	11		
Influence		11	11 (1H+5M+5L)
C and CR ?	1 (1M)		
W and WR (location of bulb+Rtot)	5 (4L+1M)		
W and WR (location of bulb)	6 (1M+5L)		
No and NoR	1 (1L)		

Pre Test

18 out of 30 students answered Question 6.c correctly.

17 out of 18 gave correct and complete explanations to their answer.

1 out of 18 gave correct but incomplete explanation to their answer.

None of the 18 students gave a correct answer by chance.

6 out of 30 students gave a wrong answer because of the location of the bulb in the circuit with reference to the other resistors (the bulb in circuit "a" is brightest because "the bulb is after the first resistor").

5 out of 30 students also gave a wrong answer (the bulb in circuit "a" is brightest because "the bulb is after the first resistor and Rtot is the same in circuits "a" and "b").

Post and Delayed-post Tests

With reference to :

a) The level of background in physics, students from a low level benefited more (13 students=10L+3M).

b) The influence from the software, students from a low and a middle level benefited more (11 students = 1H+5M+5L).

Question 6.d and Explanation 6.d (Table 4-1)

	Number of students		
	Pre	Post	Del
Question 6.d			
(c) W	11		
(a,b) C	18	30	30
(I don't know) No	1		
Explanation 6.d			
CR	17	30	30
CR ?	1		
NoR	1		
W R	11		
Influence		11	11 (1H+5M+5L)
C and CR ?	1 (1M)		
W and WR (location of bulb+Rtot)	5 (4L+1M)		
W and WR (location of bulb)	6 (1M+5L)		
No and NoR	1 (1L)		

Pre Test

18 out of 30 students answered Question 6.d correctly.

17 out of 18 gave correct and complete explanations to their answer.

1 out of 18 gave correct but incomplete explanation to their answer.

None of them gave a correct answer by chance.

6 out of 30 students gave a wrong answer because of the location of the bulb in the circuit with reference to the other resistors (the bulb in the "b" circuit is brightest because "bulb is after the first resistor").

5 out of 30 students gave also wrong answer (the bulb in circuit "b" is brightest because "the bulb is after the first resistor and Rtot is the same in circuits "a" and "b").

Post and Delayed-post tests

With reference to :

a) The level of background in physics, students from a low level benefited more (13 students=10L+3M).

b) The influence from the software, students from low and middle level benefited more (11 students = 1H+5M+5L).

Question 6 & Explanation 6

The aim and objective of Question 6 were to diagnose students' misconceptions related to the location of a bulb in more complicated circuits than of Question 1. In this case, circuits included more than two resistors in series and a variety of locations of the bulb between resistors.

In this question, two types of students' misconceptions were identified.

In the first, 6 out of 30 students claimed that the brightness of the bulb was dependent only on the location of this bulb between the resistors of a circuit.

In the second, 5 out of 30 students - although they took the Rtot of the resistors into account - claimed that the brightness of the bulb was also dependent on the location of the bulb between resistors in the circuits.

In the Post and Delayed-post tests similarly to Question 1:

* instead of using their own expressions and words some students used those provided by the software.

* all students answered correctly and gave correct and complete explanations to their answer. So they benefited from the software in that they were able to answer and correctly explain their own answers to the question.

Question 6.a and Explanation 6.a (Table 4-1)
In the Pre test, the answers to Question 6.a did not include both sorts of misconceptions. However, both sorts of sequential reasoning became noticeable in their Explanations to Question 6.a. As mentioned previously, 5 students gave the correct answer but the wrong explanation (the bulb in circuit "c" is brightest because "bulb is after the first resistor and Rtot is less than in circuit "b"). Similar findings were reported by Closset (1993).
Questions 6.b, 6.c and 6.d and Explanations 6.b, 6.c and 6.d (Table 4-1)
In the Pre test, the existence of both sorts of misconceptions (sequential reasoning) became noticeable in the students' answers and in their Explanations to Questions 6.b, 6.c and 6.d.

4.3.10 OVERCOMING STUDENTS' MISCONCEPTIONS IN ELECTRICITY: THE ROLE OF MODELS AND ANALOGIES WITH COGNITIVE CONFLICT AND DISCUSSION

As mentioned previously, many students, even those studying calculus based college physics, harbour misconceptions at a basic qualitative level, even though they may be proficient in using physics formulae. This indicates that lectures and courses need to emphasise conceptual understanding. Many misconceptions are not "miscomprehensions" of taught material but are preconceptions that students bring with them to class. It is proven that some preconceptions are more deep seated than others. Thus, not only college students who have completed a physics course at a University level (Clement 1986 & 1987, Picciarelli et al. 1991) but even teachers (Heller and Finley 1992) exhibit the same errors as students of secondary schools.

For difficult conceptual material to make sense to the students, it must be connected somehow with the students' existing knowledge. However, the students' existing intuition e.g. in the area of electricity, is often mistaken. They are globally inconsistent from a scientist's point of view; their memory can simultaneously harbour an analogical intuition and a misconception, which are diametrically opposed. This is presumably because a students' knowledge is packed in smaller pieces than a scientist's knowledge (diSessa 1985) and because each knowledge schema is activated only in certain contexts.

The teaching strategy of the software takes advantage of this fact by using discussion to promote conflict between the analogy/model and the misconception, thereby supporting conceptual change. An analogy can also serve as the metaphorical basis for a visualizable model such as the idea of the "snapping marbles" model and others. As mentioned previously Schultz et al. (1987, p. 94) point out that misconceptions can be used to advantage during instruction due to the fact that "when two convictions of a misconception are brought into conflict in a student's mind, more dissonance and more potentially useful energy is harnessed for learning than ordinary topics which do not threaten beliefs held with conviction". In this case, students can become internally motivated to understand the issue and resolve the conflict.

According to Schultz et al. (1987, p. 95), two types of conflict were used:

"a) The tension between a misconception and a correct conception in the same student and,

b) The tension between students who hold the correct point of view and students who do not.

Both tensions have the potential to create some unusually exciting and motivating discussions which should increase student involvement and retention. Skilfully led discussions appeared to be an effective vehicle for fostering dissonance, internal motivation and conceptual restructuring".

In this approach students interact with the knowledge.

As mentioned previously, because students tend to be "current minded" rather than "voltage minded", confusing cause and effect, the design of the software was based on the assumption of the electric circuit as an interactive system. It aimed at the students' understanding of this general idea and the development of students' reasoning in terms of the following aspects (Ganiel and Eylon 1987 & 1990) :

a) Quantitative relationships: ability for algebraic manipulations

b) Functional relationships: ability to consider the dynamics of the interplay between the variables in a qualitative manner.

c) Processes and macro-micro relationships: ability to associate phenomena with processes.

Actually the first two aspects are sufficient in dealing with conventional problems. It would be important for students to be able to understand the process through which, i. e. increasing the source voltage will increase the current in a circuit. The researcher's claim with regard to this aspect is that students should be able to employ microscopic considerations by using the software.
Furthermore, in designing the software, the researcher's aim is also to achieve a more meaningful understanding than a mere manipulation of numbers or algebraic terms. Operating at a level of functional relationships can help students to avoid tedious calculations and enables them to deal with the system as a whole and to consider the relationships between its parts (the global approach). Consideration of macro-micro relationships can lead to a deeper understanding of the phenomena, according to Schultz, et al. (1987), and Hartel (1993).

Pre test Phase : Misconceptions' diagnosis

Question 1 and Question 6 with the students' explanations

According to recent research, the sequential model is very common view with older students even in cases that they have already been taught the subject domain. The fact that 11 out of 30 first year university students of the sample used sequential reasoning was expected, as in other researchers' findings (Closset 1985 & 1993, Clement 1987, Picciarelli et al. 1991, Heller and Finley 1992, Unruch et al. 1997).

Especially with reference to Question 6, the view that current is "used up" by the resistors in a circuit is more persistent and prevalent than the influence of the total resistance on the current in a circuit.

5 out of the 11 students - mentioned above - emphasised the location of the bulb between the resistors although they took into consideration the total resistance in every set of circuits. Thus, in Question 6.a these students gave correct answer but wrong explanation, while in all the other cases, they gave wrong answers and wrong explanations.

6 out of the 11 students only emphasised the location of the bulb without taking into account the total resistance of a circuit. Thus, in all cases the students gave wrong answers and wrong explanations in Question 6.

Post Test Phase : Modification of students' reasoning

Question 1

Questions 1.b and 1.d were indicators of students' sequential reasoning.
So, after clicking on the answer "Stay the same" (button) that they considered as correct - as happened in Pre test - they were amazed when the message "Terrible! Try again" appeared on the screen.
According to Closset (1985) the way with which the students reacted to the cognitive conflict with their own notions was:

Firstly to "refute" results - being in doubt and asking "Why?" - because they could not understand a basic property of circuits, that current through a battery depends on all the components in a circuit.

Secondly a tendency to modify their reasoning was caused. So, they started to talk to each other and/or to the researcher. Then, they also used the facilities provided by the software.

From the "Hints" button, they were informed that the intensity (size) of current is "responsible" for any change of the brightness of the bulb. This acted as a reminder of the above mentioned basic property of circuits. Some of them managed to combine intensity (size) of current and total resistance using the Ohm's law relationship.
Some students also correlated the brightness of the bulb to the power P from the formula P=V2/R but they did not realise that this calculation referred to the total power output and not the power output of individual resistors. Thus, comparing power by comparing resistors is only justified if the current is constant (McDermott and van Zee 1985, p.p. 43-44). Being referred to the "Power" stack, they recognised the current flow as an energy flow and the

emphasis which was given to the formula P=V.i where i is the intensity of current and is the same in all components of the circuit.

For more help, they were referred to Software part 1 (Theoretical feedback) on the Current and Intensity topics by clicking the relevant buttons. As mentioned above, in all stacks the view of the circuit as an interactive system was apparent and so the quantities of current, potential difference and resistance co-existed and correlated. Students also used the term "volt" to describe the electrical pressure, but there were at least three other terms (Ampere, Ohm and Coulomb) to describe the current flow. These were also compared to a water system for "better understanding them (terms)", as students claimed.

The use of the model of snapping marbles in the stack "Current in wires" helped the students to consider the current flow as electrons flow. In this model - which was considered as "quite impressive" and attracted the students' attention more than other models - the students assumed that electrons did not come pouring out of the end of the wire like water from a pipe; instead, they sent along the energy with relatively little motion of individual electrons. The students also generated their own analogy; thus they mentioned that the action was "similar to pushing beans into a bean shooter. When the shooter is full, it is only necessary to push one bean into one end of the tube and the bean will immediately come out of the other. The individual beans do not move but the effect is almost instantaneous".

The study of electron flow at a microscopic level was also presented in some other cases, either through an anthropomorphic or through a moving-crowd model. In this view, the students examined the conventional current by calculating the speed of the free electrons of a copper wire. Thus, they were surprised to find out the time required for a bulb to light up, if a switch was turned on and the bulb and the switch was connected by a copper wire a few meters long. In reality, if you turn on the switch the light is on immediately. This fact made students to conclude that the energy transference from the first free electron to the end one was immediate.

From all the above mentioned, this view might influence the expressions and terms that the students used (8 out of 30 students in Question 1 and 11 out of 30 in Question 6). For example while on Pre test they mentioned "the resistor R2 is after the bulb so the current entering would be the same" on post and delayed-post tests they mentioned "because reducing resistance increases the flow of current" (see in the section 4. 3. 11 "Remarks on Questions 1&6 and their Explanations" in the paragraph c).

In the "Making the current flow" stack, emphasis was given to the battery (or pd. or e.m.f.) as an energy source which makes electrons move and does not create an electric charge, as the students often claimed (see some examples below) not only in the Post test phase but also in the Delayed-post test phase. For example:

Students' macroscopic notions :

"A battery creates voltage"

"Voltage causes current flow if there is a conductor present"

"If there is no pd., there is no voltage".

Students' microscopic notions :

"Electrons are pushed into the open circuit from the negative terminal"

"These electrons move through the wire freely as in a pipe until they stop at a break".

Carrying further on, the "Intensity of current" stack presented the conservation of current both in a simple circuit and at a junction. In the "Current at a junction" stack, an animation of an anthropomorphic model emphasised that "no current can be 'lost' at a junction but divides according to the resistance of each path, so that the larger fraction will go through the branch with the smaller resistance", some students commented on this. There were three different examples which helped the students to develop quantitative and functional relationships between the quantities current, voltage and resistance; and as a result of that macro-micro relationships later on, so that they acquired deeper learning.

Many students continued to explore more knowledge on the Resistance topic, as well. In the synonymous stack, the concept of resistance was introduced in the form of a metaphor such as "Resistance is the way certain substances oppose the flow of electrons" and as a result of that the size of current was reduced. An animation of flow of water in a hosepipe also followed. So, the concept was fixed to the right category in order to avoid misconceptions.

Further on, they examined the factors which influence the size of a resistance such as length, thickness and materials used at a microscopic level by using mainly cartoon models of electrical conduction etc.

For instance, in the students' comments, they mentioned that for insulators, which are considered as materials that electric current has very great

difficulty in getting through, "people keep running in mud. The way forward is blocked", in accordance with the relevant cartoon model.
Some students also said that the thickness of a wire influenced its resistance because "there is a larger area of wire for the electrons to pass along ... it is a bit like a motorway which can carry more traffic than a single-lane county road".
Additionally, they were referred to Ohm's law as a formula introduced inside a triangle. They claimed "it is easy to use the formula if you think of it as a triangle" (qualitative relationship). All the above showed the influence of resistance on the current. So, they concluded that "this (resistance) is the main way to control the current in a circuit" (functional relationship).

Going forward to add one or two resistors (either in series or in parallel), in all cases there was a special, travelling and highlighted text field, which indicated to students to note the brightness of the bulb. Thus, in the case of one resistor they mentioned "the bulb is dimmer" because "resistor is cutting down the current". At this point, analogical reasoning in the correlation between current and resistance was in progress. More explanation was provided by using animated models. Similar students' cognitive behaviour was pointed out by Stocklmayer and Treagust (1996). The researchers also claimed that anthropomorphic analogies have become popular in more recent texts, lectures and tutorials.

In the case of resistors in series, there was a simulation to a marathon race in which the runners had to come to two bridges. In a dialogue two students mentioned :
A: "... runners have to cross firstly the one (bridge) and then the other ... and all runners who cross the first bridge cross the second"
B : "... the narrow bridges slow down the whole race just as bulbs slow down the flow of electrons from the battery, the current I mean..."
A : ".. but if one of the bridges is blown up"
A and B : "the race stops"
B : ".. no runner can cross the other bridge .... this looks like removing a bulb from a circuit and stopping the electricity flow"

Similarly, in the case of resistors in parallel while observing the brightness of the bulb
A : "...the bulb is less dim than in the previous case"
B : "...because this time there are two paths for the current and in each there is only one resistor..."

A : "Yes, you see each runner has to choose which bridge to cross ... and those who cross the one do not cross the other.."
B : "... so it is easier for them to cross two bridges in parallel than in series ... and the pace of the race is faster"
A : ".. thus, bulb is less dim and actually current is more"
B : "yes, ... and if one bridge collapses the race will be slower than it was before..."
A : ".. and (the race) does not stop".

Another pair of students correlating the brightness of the bulb for resistors in series and in parallel also claimed :
A : ".. the bulb (in series resistors) is even dimmer because resistors are fighting the current"
B : "it (series resistors) may look like a resistor of longer length. To remind you from a previous stack (R=pl/s) that good conductors of electricity allow electrons to flow easily. Sometimes, though, they bump into atoms in the wire and this slows them down".
A : "Actually, this "braking effect" is called the wire's resistance. So, the longer the piece of wire, the more resistance it has".

In these dialogues, the students were influenced in their wording by the models provided and analogies of the software so they seemed to come to believe in the validity of the analogy and to correlate it to the real situation of a certain problem, in accordance with findings by Clement et al. (1987, p. 93) and Psillos & Koumaras (1993).

Finally, the results from the post and delayed-post tests showed that 12 out of 30 students might change their own model to the scientific one because of the use of the facilities provided by the software and because of the discussion with other students and the researcher.

Question 6

In this question, there was previous experience and knowledge from Question 1. Thus :

Many students (18) gave correct answers and explanations without using any of the facilities provided by the software.

A great number of students (12) also ticked on circuits for which they thought the bulb was brighter, as in Pre test. However, when they clicked on the "Finished" button they were surprised by the statement "Terrible! Try again". Their reactions were the same, as mentioned on question 1. Being in conflict with their own notions, they started a discussion to change them.

Because they were in doubt, most of them tried to use the software facilities. By clicking on the "Hints" button they were informed that the brightness of each bulb was dependent on the intensity (size) of the electric current which was flowing through; the bulb and resistors also were in series. Then they correlated the brightness of the bulb to the intensity of current which was dependant on the total resistance of a circuit and not on the number of resistors before the bulb, as they had mentioned before (using their own previous experience).
There were 6 out of 30 students who also used the Software Part 1 and they explored the same topics as in question 1. They gave more emphasis on the "Add resistors" stack and especially on resistors in series. The students presented similar cognitive behaviour as in Question 1.

Finally, as in Question 1, the results from the post tests also showed that also 12 out of 30 students (12 = 11 sequential + 1 no model) changed their sequential model to the scientific model.

Delayed-Post Test Phase : Metacognition

Question 1 and Question 6

In this phase, students were asked to answer the same questions without the facilities provided by the software after four months. All students (30) answered correctly and gave correct explanations to both Questions. While answering and explaining their answers to these Questions their cognitive behaviour was similar to the Post test phase.

In Question 1, some of them (8 out of 30 students) used the terms that they had already met when exploring the relevant section of Software Part 1 of the instructional software.
In Question 6, 11 out of 30 students did the same.
So, in both Questions they benefited from the software.

Finally, the students might adopt a nearest view to the system aspect of a simple electric circuit including just two or more resistors in series.

As mentioned in previous section, Question 8 was supplementary to both Questions 1&6 and required an advanced level of reasoning in order to be answered and to be explained completely. From the Table 4-1 and the statistical results (Appendix I) there was a small but significant increase of :

a) the number of students' correct answers to Question 8 and their explanations from the Pre to Post and Delayed-post tests

b) the mean scores of students' correct answers to Question 8 and their explanations from the Pre to Post and Delayed-post tests

Hence some students benefited from the software in this Question too.

In Question 8, the significant increase was smaller than of Questions 1&6 and Explanations because of its higher and more difficult level. However, such an increase gave added support to the results from both Questions 1&6 and Explanations. It also gave greater possibility and probability to the premise that the students adopted a viewpoint closer to the scientific model of reasoning on this sort of simple circuits.

Thus, if all students had answered correctly and had explained correctly this Question then this fact could indicate with more certainty that all students had the system view model of reasoning concerning current, voltage, resistance and energy in a simple circuit such this.

4. 3. 11 REMARKS ON QUESTIONS 1&6 AND THEIR EXPLANATIONS

a) Number of students' correct answers to the Questions 1&6 and their correct Explanations to these Questions

From Pre to Post and Delayed-post tests an increase was noticed of the number of the students' correct answers to the Question 1 (only the Questions 1.b &1.d) and the Question 6 (all the Questions 6.a, 6.b, 6.c and 6.d).

Also an increase in the number of the students' correct explanations to Question 1 (all the Questions 1.a, 1.b, 1.c and 1.d) and Question 6 (all the Questions 6.a, 6.b, 6.c and 6.d) was noticed.

a1) <u>Mean number of students' correct answers to Question 1</u>

From Table 4-1, the mean number of students who gave correct answers to Question 1 had a significant increase of 29% from Pre to Post and Delayed-post tests.

In the Pre-test the mean number of students giving correct answers was 23 out of 30 (78%). Their correct answers ranged from 57% (17 out of 30 in question 1.b) up to nearly 100% (29 out of 30 students in questions 1.a and 1.c). In the Post and Delayed-post tests all students gave the correct answers.

a2) Mean number of students' correct Explanation 1

From Table 4-1, the mean number of students who gave correct Explanations to Question 1 had a significant increase of 58% from Pre to Post and Delayed-post tests.

In the Pre-test, the mean number of the students giving correct explanations was 19 out of 30 (63%). Their correct explanations ranged from 50% (in question 1.b) up to 77% (in question 1.a).

In the Post and Delayed-post tests, all students gave the correct explanations.

a3) Mean number of students' correct answers to Question 6

From Table 4-1, the mean number of students who gave correct answers to Question 6 had a significant increase of 56% from Pre to Post and Delayed-post tests.

In the Pre-test, the mean number of the students giving correct answers was 19.25 out of 30 (64%). Their correct answers ranged from 57% (18 out of 30 in questions 6.b, 6.c, 6.d) up to 77% (23 out of 30 students in question 6.a).

In the Post and Delayed-post tests all students gave the correct answers.

a4) Mean number of students' correct Explanation 6

From Table 4-1, the mean number of students who gave correct Explanations to Question 6 had a significant increase of 74% from Pre to Post and Delayed-post tests.

In the Pre-test the mean number of the students' correct explanations was 17 out of 30 (57%).

In the Post and Delayed-post tests all students gave correct explanations to all of the Questions.

b) Mean scores of the Questions 1&6 and their Explanations

From the Tables of the results of the Analyses of Variance tests (ANOVA test) and of Wilcoxon test (see Appendix I), students presented a statistically significant increase in the mean scores in Questions 1&6 and in their Explanations to these Questions from the Pre to Post tests and no difference from the Post to Delayed-post tests.

Question 1 and Explanation 1

Question 1

	Students' mean scores			(%) increase	(%) mean
	Pre	Post	Del	of mean scores	increase
1.a	2.933	3	3	2	
1.b	2.133	3	3	41	20
1.c	2.933	3	3	2	
1.d	2.2	3	3	36	

Explanation 1

	Students' mean scores			(%) increase	(%) mean
	Pre	Post	Del	of mean scores	increase
1.a	2.6	3	3	15	
1.b	1.933	3	3	55	35.75
1.c	2.4	3	3	25	
1.d	2.033	3	3	48	

Question 6 and Explanation 6

Question 6

	Students' mean scores			(%) increase	(%) mean
	Pre	Post	Del	of mean scores	increase
6.a	2.5	3	3	20	
6.b	2.167	3	3	38	33.5
6.c	2.167	3	3	38	
6.d	2.167	3	3	38	

Explanation 6

	Students' mean scores			(%) increase	(%) mean
	Pre	Post	Del	of mean scores	increase
6.a	2.133	3	3	41	
6.b	2.133	3	3	41	41
6.c	2.133	3	3	41	
6.d	2.133	3	3	41	

The above results showed that :

1) Overall students gained benefit from the software especially with the Questions 1&6 because the mean increase of the mean scores of :

a) the students' correct answers to Question 1 was 20%

b) the students' correct answers to Question 6 was 33.5%

c) the students' correct Explanations to Question 1 was 35.75%

d) the students' correct Explanations to Question 6 was 41%

2) In the Post and Delayed-post tests for both Questions 1&6 and their Explanations students' mean scores were 3, while in the Pre-test they ranged from 2.133 (Question 1.b) and 1.933 (Explanation 1.b) up to 2.933 (Questions 1.a and 1.c) and 2.6 (Explanation 1.a).

3) With reference to the level of the background knowledge in physics :

a) As a result of the above mentioned students' population became completely homogeneous in Post and Delayed-post tests.

b) As a result of previously mentioned (see Chapter 3) Low and Middle level students benefited.

So, in each of the Questions and Explanations the students who benefited were :

	Question	Explanation
1.a	1 student = 1L	7 students = 6L+1H
1.b	13 students = 10L+3M	15 students = 10L+5M
1.c	1 student = 1L	8 students = 7L+1H
1.d	12 students = 10L+2M	14 students = 10L+3M+1H
6.a	6 students = 5L+1M	13 students = 10L+3M
6.b	12 students = 10L+2M	13 students = 10L+3M
6.c	12 students = 10L+2M	13 students = 10L+3M
6.d	12 students = 10L+2M	13 students = 10L+3M

Consequently :

In Questions 1.b and 1.d

All students of the Low level of background knowledge in physics benefited while 3 out of 10 (30%) students of the Middle level improved their answers in the Question 1.b and 2 out of 10 of them (20%) to the Question 1.d.

Thus, on an average 25% of the Middle level students improved their answers to the Questions 1.b and 1.d.

In Explanations 1.b and 1.d

All the Low level students benefited,

while 5 out of 10 (50%) of the Middle level students improved their explanations to Question 1.b and 3 out of 10 of them (30%) to the Question 1.d.

Thus, on an average 40% of the Middle level students improved their Explanations 1.b and 1.d.

In Questions 6.a, 6.b, 6.c, 6.d

All the Low level students benefited,

while 5 out of them (50%) in Question 6.a.

In the case of the Middle level students 2 out of 10 (20%) improved their answers to Questions 6.b, 6.c, 6.d and 1 out of 10 (10%) to the Question 6.a.

Thus, on an average 15% of the Middle level students improved their answers to all of Questions 6.

In Explanations to Questions 6.a, 6.b, 6.c and 6.d

All of the Low level students benefited

and 3 out of 10 (30%) Middle level students improved their Explanations.

In general all students benefited from the use of the software, as did the students in the study by Watkins, Augusti and Calverley (1997). In particular the performance of weaker students increased more.

c) Influence on students' wording in Questions and Explanations 1&6 from the software

From the results mentioned previously, a change was noted in the students' own wording while explaining their answers to Questions 1&6 in the Post and Delayed-post tests. This change can be interpreted as an influence by the software because of the provided models and analogies concerning some electrical concepts. According to their comments in the Questionnaire the software introduced them to another way of reasoning by linking the familiar to the unfamiliar knowledge, that means concrete to abstract concepts. The new way of reasoning should cause the change of words and expressions while formatting their own explanations in the Post and Delayed-post phase.

c1) With reference to the students' level of background knowledge in physics

From the analysis of the results of the Questions and Explanations 1&6 (see the previously mentioned "Influence") mainly Low and Middle level students were influenced, this was recorded by the change of their expressions. Thus :

In their Explanations to Question 1,
there were 8 students were influenced:

1 of them was of the High level,
4 of them was of the Middle level
3 of them was of the Low level.

In their Explanations to Question 6,
there were 11 students were influenced :

1 of them was of the High level,
5 of them was of the Middle level
5 of them was of the Low level.

c2) With reference to the students' explanations in the Pre test

Not only students who explained incorrectly and students who did not explain the questions at all, but also students who explained correctly and completely the questions in the Pre-test were influenced by the software. Examples of this influence are provided in the Appendix II (p. 324).

Thus :

1) Students who gave wrong answers and wrong explanations

In the Pre test there were students who answered incorrectly because of their sequential reasoning being embedded in their explanations.

However, in the Post and Delayed-post tests these students not only answered correctly but also they used words which were indicative of the influence of the software mainly from the relevant models and analogies of the electrical concepts provided (See Appendix II p. 324).

2) <u>Students who gave correct answer and wrong explanation</u>

In the Pre test, although they ticked the correct response only for Question 6.a some students explained the question incorrectly because they took into consideration the total resistance and the location of the bulb between them.

In the Post and Delayed-post tests they answered and explained correctly. Also they used words which were indicative of the influence from the software (See Appendix II p. 324).

3) <u>Students who gave correct answer and no explanation</u>

In the Pre test, students ticked the correct answer either by guessing or by chance and so they could not explain their answer.

In the Post and Delayed-post tests they were influenced by the software, e.g. in question 1.b "the resistance to the flow of electrons increased and so the current decreased and the brightness of the bulb decreased" (1M) (See Appendix II p. 324).

4) <u>Students who gave correct answer and correct explanation</u>

Even students, who ticked the correct answers and explained the questions correctly and completely in the Pre test, were influenced by the software because they changed their own wording in the Post and Delayed-post tests.

In this case, not only Middle but also High level students were included (See Appendix II p. 324).

5) <u>Students who gave no answer and no explanation</u>

In the Pre test only one student (15L) ticked "I don't know" and did not give any explanation to all of Questions 6.

However, in the Post and Delayed-post tests s/he not only ticked the correct answer and explained correctly and completely all the Questions 6 but also s/he was influenced by the software due to the change of his/her wording and emphasised the independence of the brightness of the bulb referring to its position between the resistors in a circuit, as well (See Appendix II p. 324).

The above results showed that:

Overall, students were influenced by the software.

With reference to :

a) The level of their background knowledge in physics, Middle and Low level students were influenced more.

b) The correctness and incorrectness of their answers and their explanations to Questions in the Pre test, taking into account all the possible combinations between answers and explanations , i. e.:

C and CR : correct answer and correct explanation,

C and CR? : correct answer and correct but incomplete explanation, C and NoR : correct answer and no explanation,

C and WR : correct answer and wrong explanation,

W and WR : wrong answer and wrong explanation,

No and NoR : no answer and no explanation (see Chapter 3, p. 148), students should be also influenced by the software in Questions 1&6. However, the results mentioned constitute only an indication of the influence of the software on students' reasoning because a larger sample was required in order to give more than 8 and 11 students influenced by software.

d) Sequential reasoning

In the Pre test phase of this research, the results of the students' answers and their explanations to Questions 1&6 revealed that 11 out of 30 students had sequential reasoning concerning the concepts of current, potential difference or voltage, resistance and energy in circuits with resistors in series.
There was also 1 out of 30 students who had no model.

Especially, in Questions and Explanations 6, it became clear that two sorts of students' misconceptions appeared essentially because of their sequential model of reasoning.

In the first, there were 6 students who claimed that the brightness of the bulb was dependent only on the location of this bulb between the resistors of a circuit.

In the second, there were 5 students who - although they took into account the Rtot of the resistors - supported that the brightness of the bulb was also dependent on the location of this bulb between resistors in the circuit.

As previously mentioned in this Chapter, Logan (1981), Duit (1985) and Jung (1985) claimed that many learning difficulties in electricity instruction were partly induced by everyday language. In some cases, there is a tendency to think in sequences of single "cause-event-elements" which is not appropriateto electricity and has an important impact on learning electrical concepts. Students concentrate on local process and prefer sequential reasoning when dealing with problems involving the electric circuit. They seem to have severe difficulties in taking all parts of a circuit into consideration. They seem to be almost unable to think of the circuit in terms of a system.

In Questions 1.b and 1.d

11 students answered "stay the same" because of the position of the bulb between two resistors in series. They meant that the resistor which was increased or decreased was after the bulb and so had no influence on brightness of the bulb.

In Question 6.a

6 out of the 11 students ticked the wrong answers (circuits) and explained their answers incorrectly. So, they mentioned that the bulbs in circuits "b" and "c" were brighter than in circuit "a" because in both cases "bulb is after the first resistor".

5 out of the 11 students although they ticked the correct answer they explained their answer incorrectly. So, they mentioned that the bulb in circuit "c" was the brightest because " in circuit "c" the bulb is after the first resistor and the Rtot is less than in circuit "b" ".

In Question 6.b

6 out of the 11 students gave wrong answer because of the location of the bulb in the circuit with reference to the other resistors. They mentioned that the bulb in circuit "c" is brightest because "bulb is before the first resistor".

5 out of the 11 students gave also wrong answer. They mentioned that the bulb in the "c" circuit is brightest because "bulb is before the first resistor and Rtot is the same in all circuits ".

In Question 6.c

6 out of the 11 students gave wrong answer because of the location of the bulb in the circuit with reference to the other resistors. They mentioned that the bulb in circuit "a" is brightest because "bulb is after the first resistor".

5 out of the 11 students gave also a wrong answer. They mentioned that the bulb in circuit "a" is brightest because "bulb is after the first resistor and Rtot is the same in circuits "a" and "b" ".

In Question 6.d

6 out of the 11 students gave a wrong answer because of the location of the bulb in the circuit with reference to the other resistors. They mentioned that the bulb in circuit "b" is brightest because "bulb is after the first resistor".

5 out of the 11 students gave also a wrong answer. They mentioned that the bulb in circuit "b" is brightest because "bulb is after the first resistor and Rtot is the same in circuits "a" and "b" ".

Table 4-2

Examples of students' sequential reasoning

Such an inability to think in interactions rather than in single "cause-event-elements" hampers human understanding not only in electricity but also in other fields.

Many researchers supported that this sort of reasoning is dominant even in secondary students of older ages (Hartel 1993 and Unruh et al. 1997) and very persistent even in physics and engineering graduates training to be teachers [Shipstone (1984) and Picciarelli et al. (1991)] and in secondary school teachers (Heller and Finley 1992). Thus, the fact that 11 students of a University level had sequential reasoning was expected.

From the above-mentioned, in Questions 1.b, 1.d, 6.a, 6.b, 6.c and 6.d there were 11 students who explained the brightness of the bulb in the circuits due to the location of the bulb between the other two, three or more resistors of the circuits. As mentioned in Chapter 1 and in previous section of this Chapter, the students' responses of the "before and after" nature correspond either to the "sequence" model of current flow (Shipstone 1984) or to the use of a "time dependent" model for current (Riley et al. 1981) or to using "sequential reasoning" (Closset 1983).

In addition, in Question 6.a, 6.b, 6.c and 6.d, 5 students explained the brightness of the bulb in the circuits taking into consideration not only the location of the bulb between the other two or three or more resistors of the circuits but also the Rtot of the resistors in the circuits. These students had another form of the "sequential reasoning" for the concept of current because they only stated Rtot without being able to apply the formula and to achieve a more meaningful understanding of the functional relationships between current, pd. and resistance than a mere manipulation of algebraic terms or numbers (Ganiel and Eylon 1987). As it is clear from the results, these students did not take into consideration the Rtot of the resistors as a controller of the current in the whole circuit.
For example, in Question 6.c, although they stated the Rtot, the "before" and "after" error was imperative in their thinking and so they chose circuit "a" as correct (its bulb the brightest) instead of circuit "c", which was really the correct one.

In a study referring to the meaning of current in the everyday language of some countries and its consequences for understanding the electric circuit, Duit (1985) claimed that students misunderstood the flow of charge meaning of current with the flow of energy. Thus, they considered current as an

"energy-like-entity" which is consumed in the bulb, i.e. "it is used up while changed into light and heat" (students' comment in this research).
As previously mentioned prior to instructional software, the students' explanatory system is in the form of simple linear causality involving one single variable. In students' causality "current" is the sole variable which explain the brightness of the bulb and the running down the battery.

The results of this research supported that 11 out of 30 students shared a common set of propositions which made up a coherent but incorrect sequential model of current flow. Thus, the students' beliefs were that:
1) The battery acts as a source of current;
2) It releases a fixed amount of current (energy) which circulates around the circuit;
3) The fixed current is not modified until it reaches a resistor or a bulb;
4) Resistors and bulbs use up or consume the current;
5) The brightness of a bulb depends on the amount of current passing through the bulb;
6) The current is consumed or used up by each component of the circuit;
7) Where there is more than one bulb or resistor in a circuit path then the last resistor or bulb receives less current.
According to their beliefs the circuit was not regarded as a system which is independent of time, but rather in time-dependent sequences. This is an atomistic way of looking at the parts of the circuit, piece by piece, step by step. Students attempted to assimilate the assumption that current circulates in the circuit to the conception of a linear transmission of energy. This resulted in the sequential reasoning or the current consumption model.

In the Post and Delayed-post tests, not only students who seemed to be influenced on their wording, but also students who seemed not to be influenced, gained from the software, because they answered correctly and explained completely and correctly their answers.

It is worth mentioning that few students (4 students), who were influenced in their answers and explanations by the introduction of another way of reasoning provided by the software, not only answered correctly and explained their answers correctly but also emphasised the "before and after" error in their explanations, i.e. claiming "the position of the bulb does not matter; the brightness of the bulb is the same because there are two resistors in all the circuits" in Question 6.b.

As mentioned previously (see previous section "Useful models and analogies in electricity" in this Chapter), the students of this research considered that the battery is the cause of the bulb brightness and it gives "current", without differentiating between the time duration and a given time instant.
To bridge the gap between students' and scientists' models, the instructional software provided causal qualitative (macroscopic) models transposed from physics, such as :
a) the flow model which brings the physical quantities of voltage, current, resistance and their interrelationships into play;
b) the energy flow model which brings the physical quantities of energy and time into play.

Finally, within the flow aspect of current introduced by the models and analogies provided for both Questions, 12 out of 30 students (11 sequence model + 1 no model) conceived the system view of the circuit and considered the role of the current as a transporter of the electrical energy in a circuit.
So, in the Post and Delayed-post tests the students stated that the current consists of a flow of electric charges through the circuit; that these charges gain electrical energy in passing through the battery and carry this energy to the bulb; once there they give up the electrical energy which is used to produce light and heat, and return to the battery where the cycle recommences.

4. 3. 12 CONCLUDING REMARKS ON THE ANALYSES OF THE QUESTIONS 1&6 AND THEIR EXPLANATIONS

All the above-mentioned proved that:

1) A diagnosis of students' sequential reasoning existed.

2) There was an increase in the number of the students' answers and their explanations to the Questions 1&6 in the Post and Delayed-post tests.

3) There was also an increase in the mean scores of the students answers and of their explanations to the Questions 1&6.

4) Overall students benefited using the software; students of the Low and Middle level background knowledge in physics gained more benefit.

5) There existed a satisfactory number of students who changed their wording while explaining their answers to the Questions 1&6 because of the influence of the software on their thinking.

No of Questions		PRE - TEST								POST - TEST								DELAYED - POST - TEST							
		Questions/Answers PRE				Explanations PRE				Questions/Answers POST				Explanations POST				Questions/Answers DEL				Explanations DEL			
		C	C?	W	No	CR	CR?	WR	NoR	C	C?	W	No	CR	CR?	WR	NoR	C	C?	W	No	CR	CR?	WR	NoR
1	1a	29		1		23	4	1	2	30				30				30				30			
	1b	17		13		15	1	11	3	30				30				30				30			
	1c	29		1		22	2	2	4	30				30				30				30			
	1d	18		12		16	1	11	2	30				30				30				30			
2	2a	10		20		7	2	19	2	27		3		23	3	2	2	27		3		21	2	2	5
	2b	10		20		7	2	18	3	27		3		24	2	2	2	27		3		20	3	2	5
3	3a	29		1		21	3	4	2	30				28	1	1		30				27	1		2
	3b	22		7	1	16	5	6	3	29		1		24	5	1		29		1		23	4		3
	3c	6		24		1	3	22	4	26		4		21	4	3	2	25		5		18	5	3	4
4	4	14		14	2	11	2	13	4	29		1		27	2	1		29		1		21	5	1	3
5	5a	30				30				30				30				30				28	1		1
	5b	11		17	2	11		17	2	30				27	3			30				22	5		3
6	6a	23		6	1	17	1	11	1	30				30				30				30			
	6b	18		11	1	17	1	11	1	30				30				30				30			
	6c	18		11	1	17	1	11	1	30				30				30				30			
	6d	18		11	1	17	1	11	1	30				30				30				30			
7	7	9		19	2	9		17	4	28		1	1	26	1	1	2	27		2	1	24			6
8	8	3	12	14	1	1	6	11	12	12	16	1	1	9	16	1	4	9	13	6	2	4	9	3	14
9	9	1	10	17	2	1	9	11	9	14	14	2		10	10	2	8	9	14	5	2	7	10	3	10
10	10	3	22		5		8		22	19	9		2	7	14		9	21	6		3	3	9		1

Exercise			PRE-TEST	POST-TEST	DELAYED-POST TEST
Excellent	=	4		11	6
Good	=	3	7	8	9
Fair	=	2	5	10	13
Poor	=	1	6	1	1
No	=	0	12		1

Table 4-1

Students' Performance on Questions, Explanations and Exercise in the Pre-test, the Post-test and Delayed-Post test

Question 1

The software provides a logical sequence of data analysis step by step from simple to complex.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	22	4	2	
* Positive explanations				
Theory + Questions				
1	7			
Questions				
1	15			
* No Explanation				
		1		
* Negative explanations				
With reference to logical				
		1	1	
Same info. again + again				
			1	
In some subjects				
		1		
HyperCard style				
		1		

Table 4-Q1
Questionnaire: Question 1

Question 2

The software provides activities which encourage learners to explore the information.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	24	4		
* Positive explanations				
Theory				
1	8			
Theory + Hints				
1	16			
* No explanation				
		2		
* Negative explanations				
may generate interest, but not always				
		2		

Table 4-Q2
Questionnaire: Question 2

Question 3

The software provides activities which encourage students to plan their solution systematically (step-by-step analysis of what they did and how they did it).

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
3	16	8	3	
* Positive explanations				
Text-field +Theory				
2	6			
Text-field + Hints + Theory				
1	9			
* No explanation				
	1	7		
* Negative explanations				
More logical progression				
			1	
Guessing				
			2	
Some questions confusing				
		1		

Table 4-Q3
Questionnaire: Question 3

Question 4

The software provides activities which encourage students to think about their thinking (e.g. define a problem, plan a solution).

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
3	22	4	1	
* Positive explanations				
Text-field + Hints + Theory				
1	8			
Hints + Theory				
	11			
Theory				
2	1			
* No explanation				
	2	4		
* Negative explanations				
No coherent path				
			1	

Table 4-Q4
Questionnaire: Question 4

Question 5

The software encourages students to try alternative solutions to questions.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
4	21	5		
* Positive explanations				
Multiple choice + 2 or 3 chances				
4	15			
Multiple choice + 2 or 3 chances + 2 correct answers				
	4			
2 correct answers				
	2			
* No explanation				
		5		

Table 4-Q5
Questionnaire: Question 5

Question 6

The software encourages students to use systematic methods for locating and fixing mistakes.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	23	4	1	
* Positive explanations				
Theory (only)				
1	7			
Hints + Theory				
1	16			
* No explanation				
		2		
* Negative explanations				
with reference to systematic				
		2	1	

Table 4-Q6
Questionnaire: Question 6

Question 7

The software encourages the breaking down of complex problems into smaller and simpler problems.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
6	12	11	1	
* Positive explanations				
Questions only				
3	7			
Theory only				
1	3			
Theory + Questions				
2	2			
* No explanation				
		10		
* Negative explanations				
Only in some cases				
		1		
Wording not clear				
			1	

Table 4-Q7
Questionnaire: Question 7

Question 8

The software promotes collaborative learning and shared problem-solving.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
	19	7	3	1
* Positive explanations				
Talk with others (only)				
	2			
Talk with others + decide together				
	17			
* No explanation				
		7		
* Negative explanations				
Individual learning				
			3	1

Table 4-Q8
Questionnaire: Question 8

Question 9a

The software was easy to use.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
3	22	2	3	
* Positive explanations				
No knowledge				
1	18			
No skills				
	14			
Operation simple				
1	8			
User-friendly				
1	14			
Clearly laid out				
	2			
* No explanation				
		1	1	
*Negative explanations				
Not always easy				
		1		
Round in circles				
			1	
Buttons' difficulty				
			1	

Table 4-Q9a
Questionnaire: Question 9a

Question 9b

The software was enjoyable.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
4	25	1		
* Positive explanations				
Smart illustrations and animated pictures				
4	19			
Fun with theory				
	18			
Another way of thinking (easier understanding)				
2	9			
Enjoy a challenge				
	11			
Theory directly available				
	3			
* No explanation				
		1		

Table 4-Q9b
Questionnaire: Question 9b

Question 9c

The software was interesting.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
5	21	3	1	
* Positive explanations				
Animations + illustrations				
2	15			
Theory directly found + taken, in details				
1	15			
Another way of thinking				
2	7			
Way of presenting information				
	9			
Lots of choices to see + do, theory put into practice				
	3			
Good experience				
	1			
* No explanation				
		2		
* Negative explanations				
To some degree				
		1		
Shorter sessions				
			1	

Table 4-Q9c
Questionnaire: Question 9c

Question 10a

The software session was useful for presenting (introducing) essential concepts in electricity.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	21	3	4	
* Positive explanations				
Theory: illustrations + animated pictures				
1	8			
Different ways of thinking				
	14			
Ways of presenting information				
1	5			
* No explanation				
	5	2		
* Negative explanations				
In a broad sense				
		1		
Too basic				
			2	
Shorter sessions				
			1	
Prefer notes				
			1	

Table 4-Q10a
Questionnaire: Question 10a

Question 10b

The software session was useful for increasing knowledge of these essential concepts.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
4	21	2	3	
* Positive explanations				
Direct use of theory well done + enlightening				
2	9			
Another way of reasoning				
1	8			
Illustrations + animated pictures				
1	5			
* No explanation				
	5	2		
* Negative explanations				
Prefer notes				
			2	
Shorter sessions				
			1	

Table 4-Q10b
Questionnaire: Question 10b

Question 10c

The software session was useful for stimulating interest in these concepts.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	20	5	3	
* Positive explanations				
Wanting + giving info., fully analysed (theory) + simple way				
2	11			
Illustrations + animated pictures : presentation nice				
	12			
Another way of thinking				
	10			
* No explanation				
		3	1	
* Negative explanations				
Not particularly				
		2		
Prefer notes				
			1	
Shorter sessions				
			1	

Table 4-Q10c
Questionnaire: Question 10c

Question 11

I would like to spend more time using this software.

N = 30 students

Strongly Agree SA	Agree A	Undecided UnD	Disagree D	Strongly Disagree SD
2	18	3	5	2
* Positive explanations				
Theory				
1	12			
Theory + questions				
1				
Theory + HyperCard				
	6			
Another way of thinking				
	4			
Interesting + fun				
	4			
* No explanation				
		3	3	1
* Negative explanations				
Prefer paper + pencil				
			2	1

Table 4-Q11
Questionnaire: Question 11

Question 12

Could you, please, circle all the ways which you have previously covered the content (electricity) of the software.

N = 30 students

Ways of work previously done on electricity		Students
Lectures		30
Practicals		30
Tutorials		30
Textbooks		30
Essays		1
Other:	Video	1
	Computer programme	6

Table 4-Q12
Questionnaire: Question 12

Question 13

How does the software compare to the teaching you have previously encountered?

N = 30 students

Positive comments	
Presentation of info in a remarkable way} Another way of thinking}	19 students
Good idea (experience)! I enjoyed it.	12 students
Deeper understanding} Possibility to explain}	10 students
Stimulated interest on the subject domain	9 students
Availability of theory (when needed)	8 students
Software as a supplement of teaching	5 students
Consolidation of knowledge	2 students
Negative comments	
Too basic	1 student

Table 4-Q13
Questionnaire: Question 13

Question 14

Have you, in the last month, done any extra work on the content (electricity) of the software?

Question 15

If yes, how often and what methods did you use (lectures, read book and references etc)?

N = 30 students

Extra work done on electricity in the last month	Students
1st year course (lectures, tutorials, practicals, textbooks)	22
Revision session (3 hours)	8

Table 4-Q14 & 15
Questionnaire: Questions 14 & 15

Question 16

What do you feel you have gained, if anything, from the software?

Total Number of Students N = 30 students	
Positive comments	29 students
a) Another way of reasoning	19 students
b) More learning and clearer info} better/more understanding - explain}	17 students
c) Skills on drawing graphs through the provided spreadsheet from the software	14 students
d) Consolidate their knowledge	13 students
e) Computing skills on HyperCard	12 students
f) Talk with the researcher - to draw inferences on various topics	11 students
No comment	1 student

Table 4-Q16
Questionnaire: Question 16

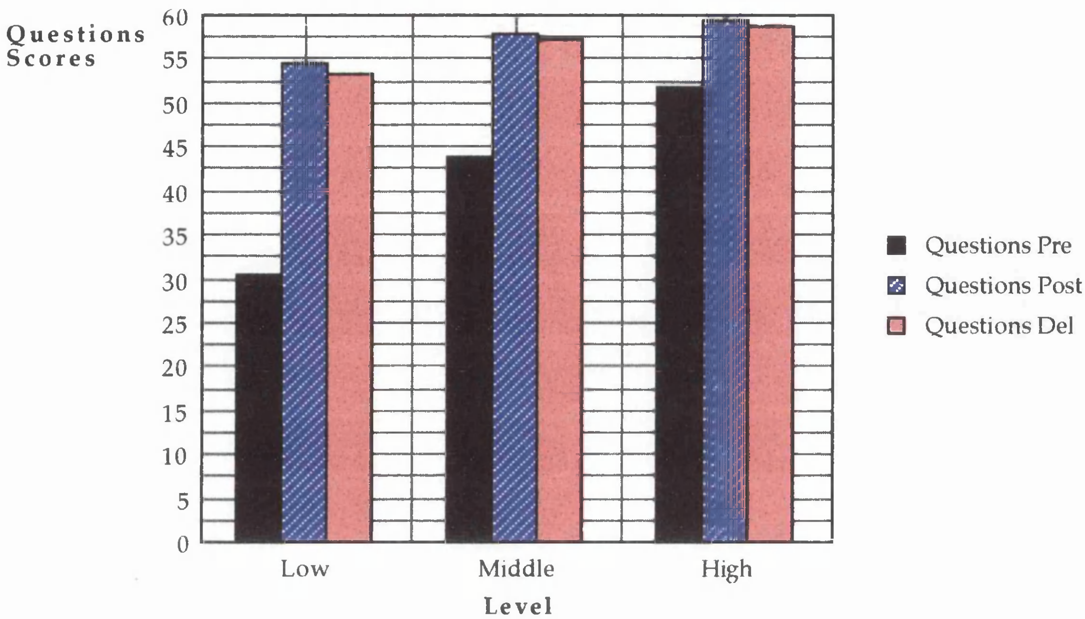


Figure 4-1
Differences in Questions scores among students with different levels of physics background

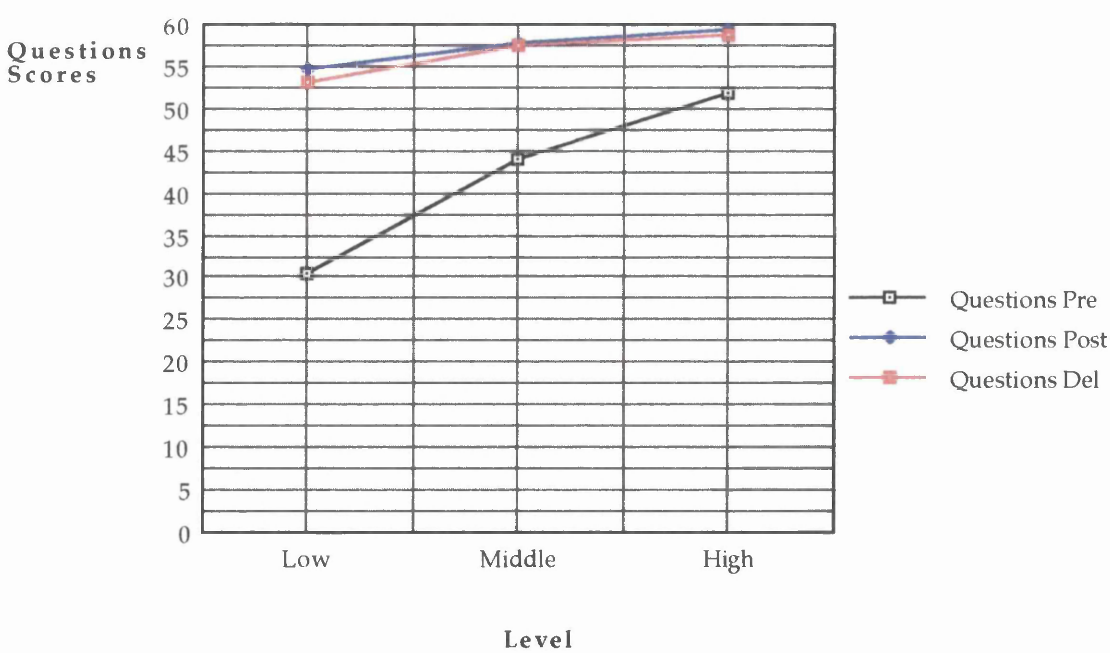


Figure 4-2
Differences in Questions scores among students with different levels of physics background

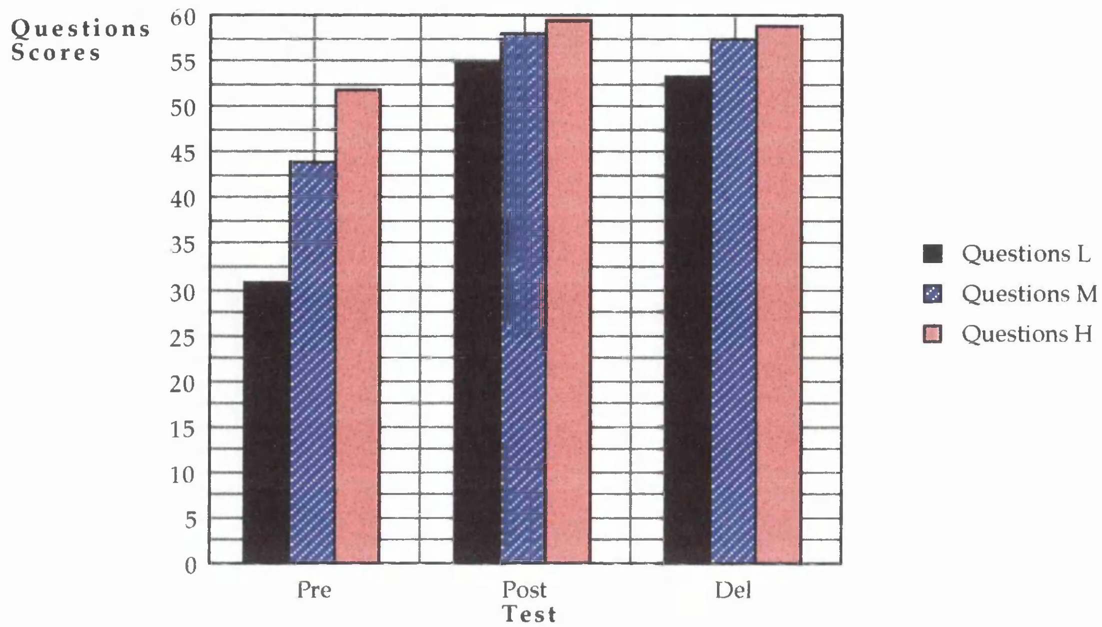


Figure 4-3
Differences in Questions scores among students in Pre, Post and Delayed-post tests

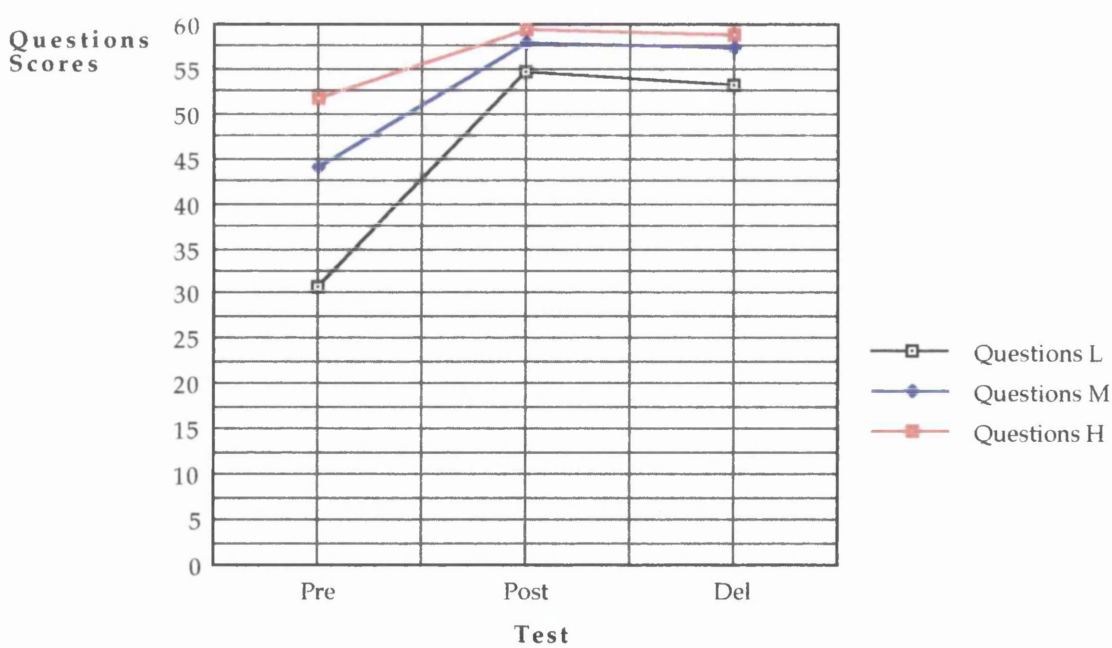


Figure 4-4
Difference in Questions scores among students in Pre, Post and Delayed-post tests

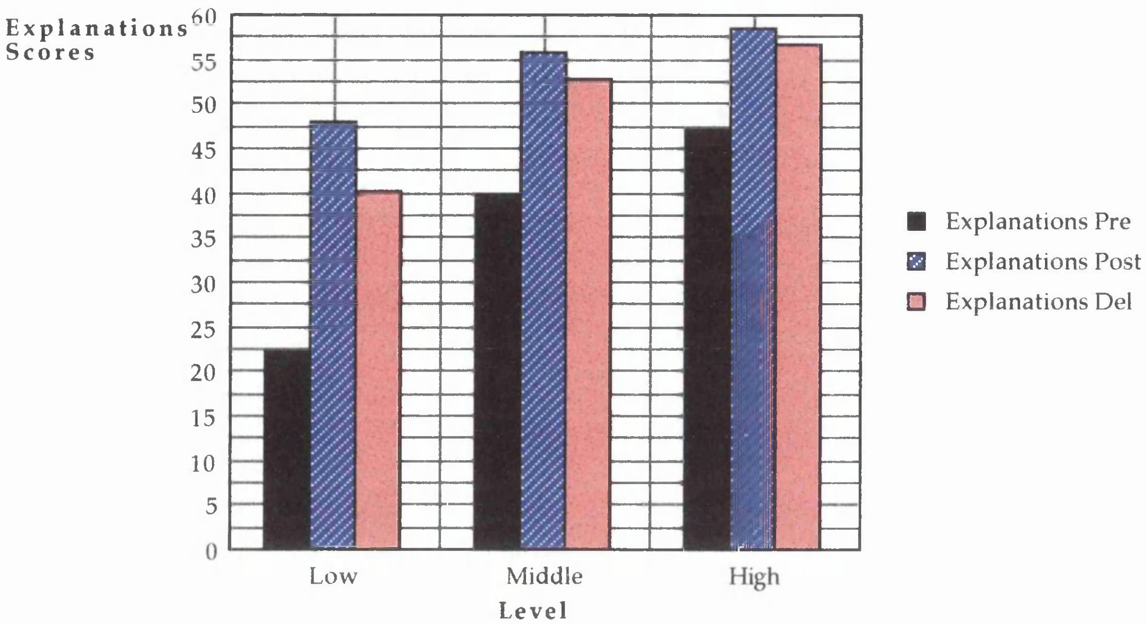


Figure 4-5
Differences in Explanations scores among students with different levels of physics background

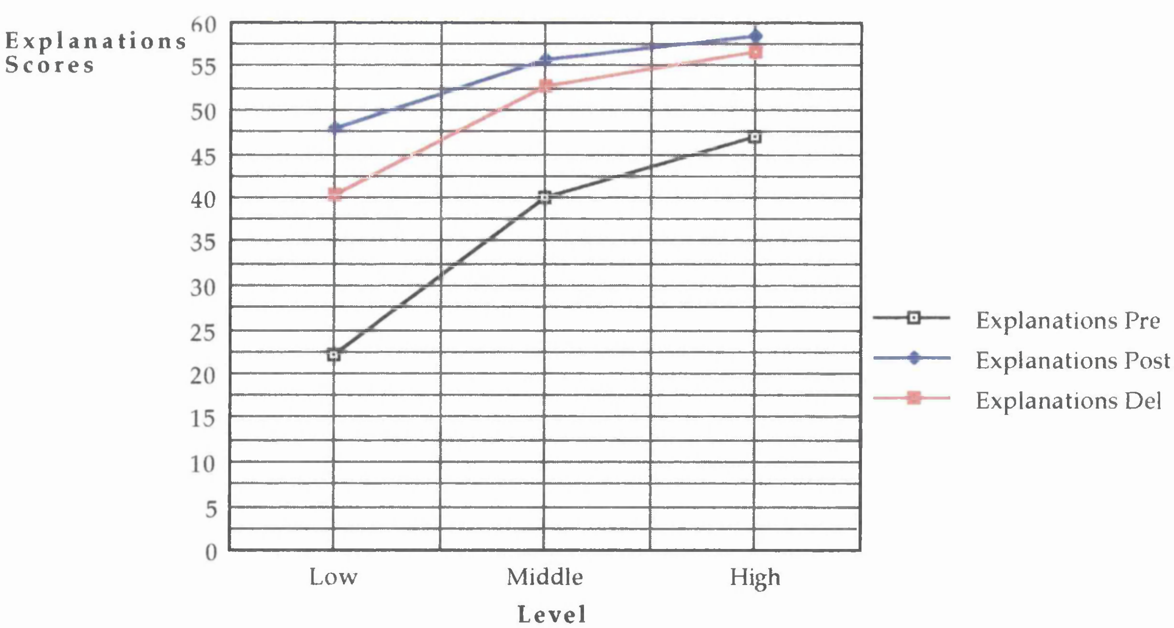


Figure 4-6
Differences in Explanations scores among students with different levels of physics background

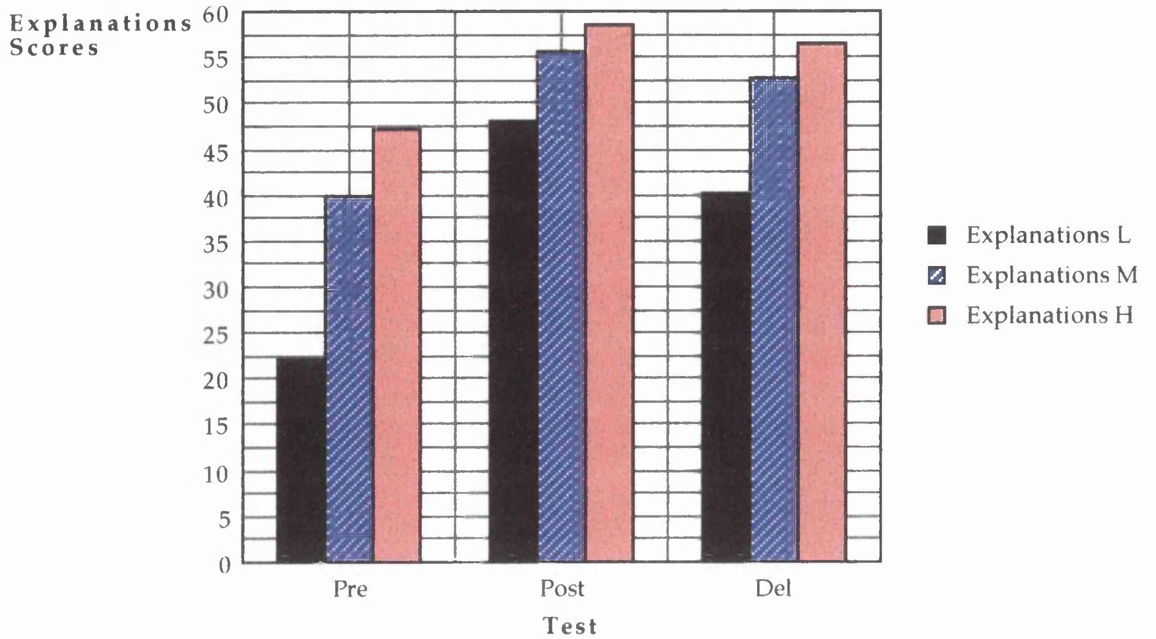


Figure 4-7
Differences in Explanations scores among students in Pre, Post and Delayed-post tests

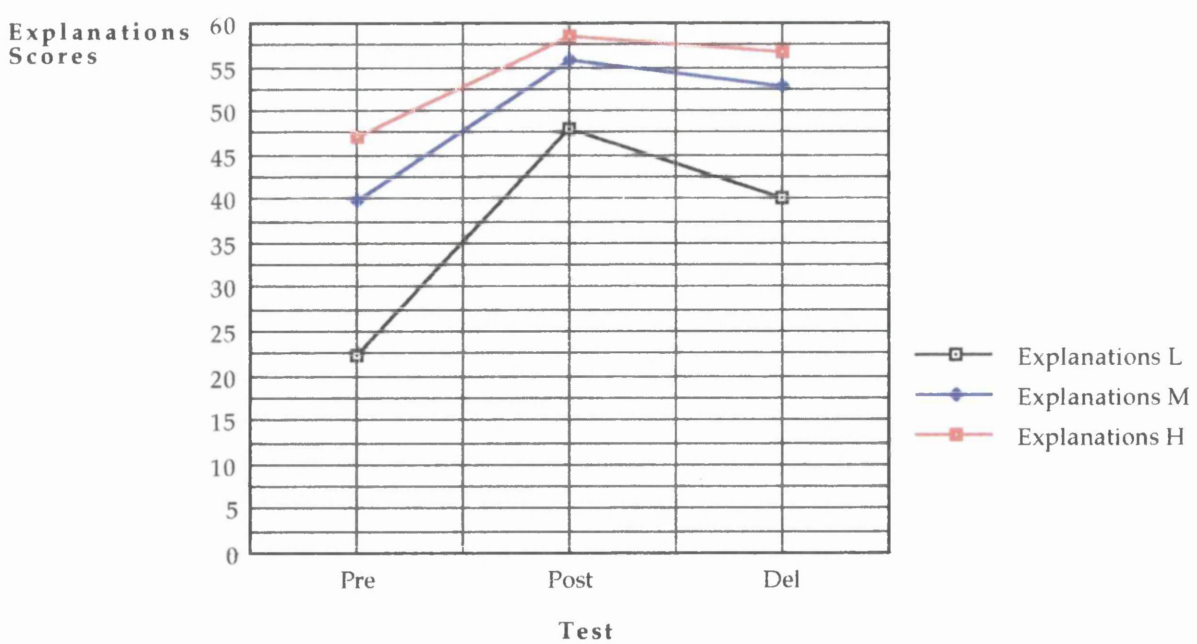


Figure 4-8
Differences in Explanations scores among students in Pre, Post and Delayed-post tests

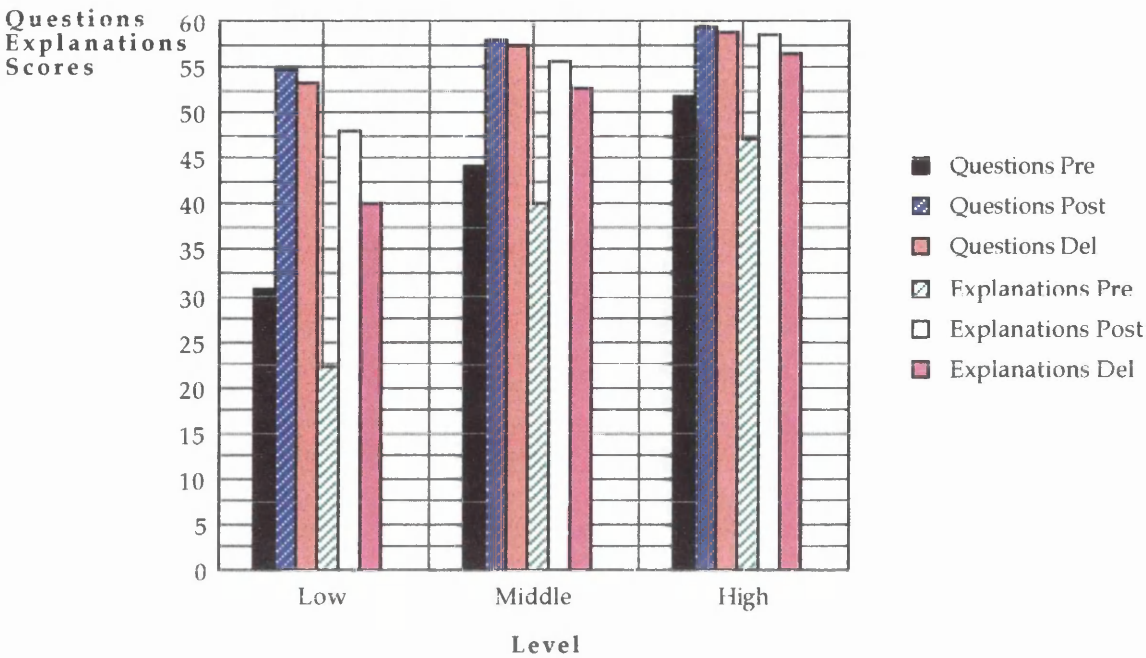


Figure 4-9
Differences in Questions/Explanations scores among students with different levels of physics background

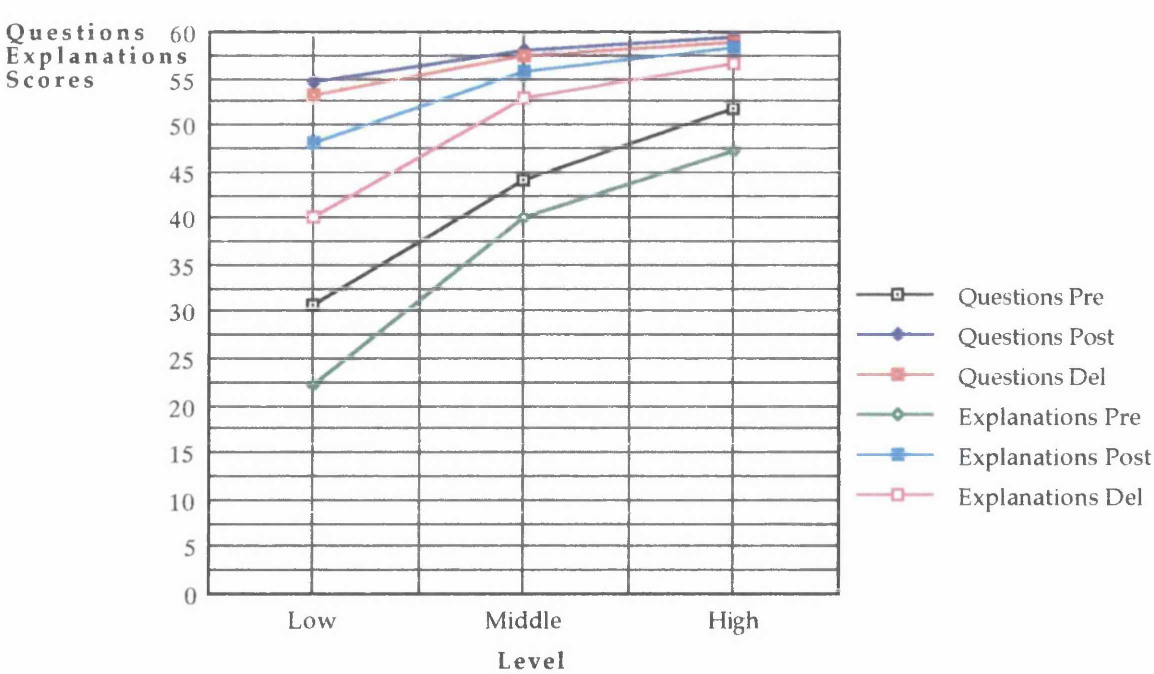


Figure 4-10
Differences in Questions/Explanations scores among students with different levels of physics background

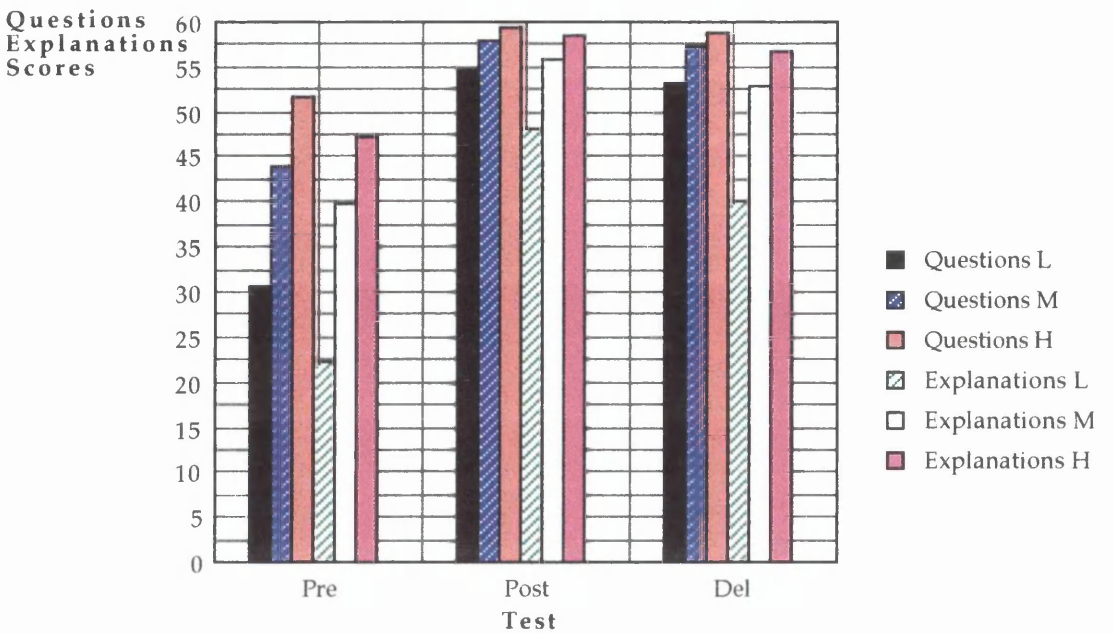


Figure 4-11
Differences on Questions/Explanations scores among students in Pre, Post and Delayed-post tests

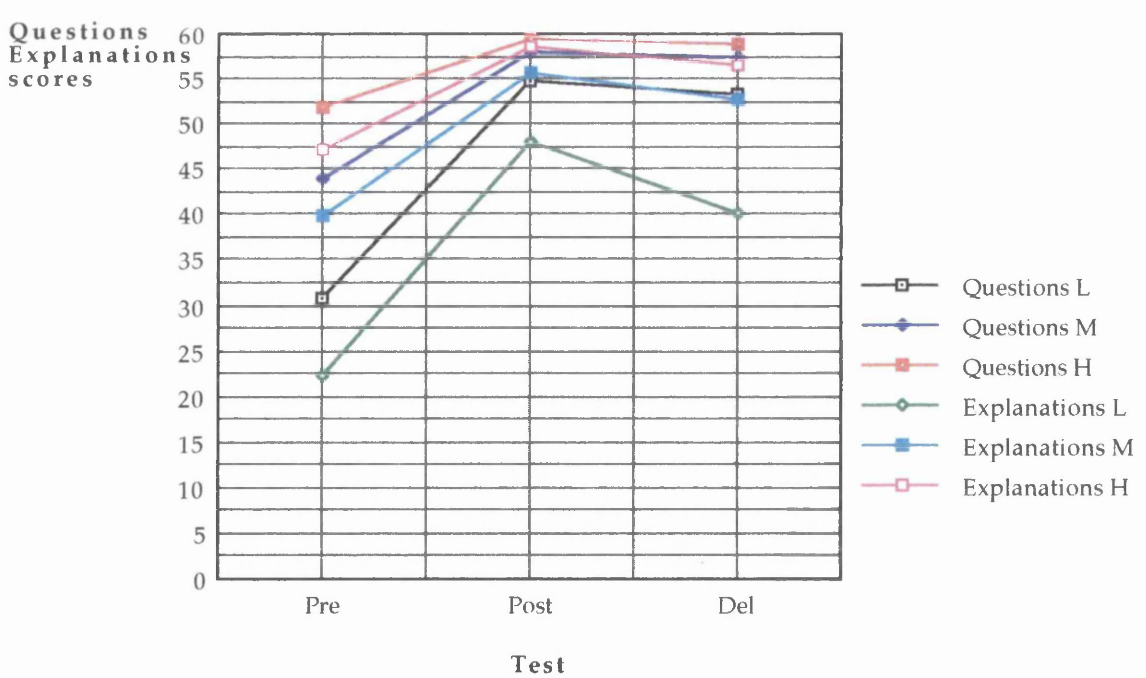


Figure 4-12
Differences in Questions/Explanations scores among students in Pre, Post and Delayed-post tests

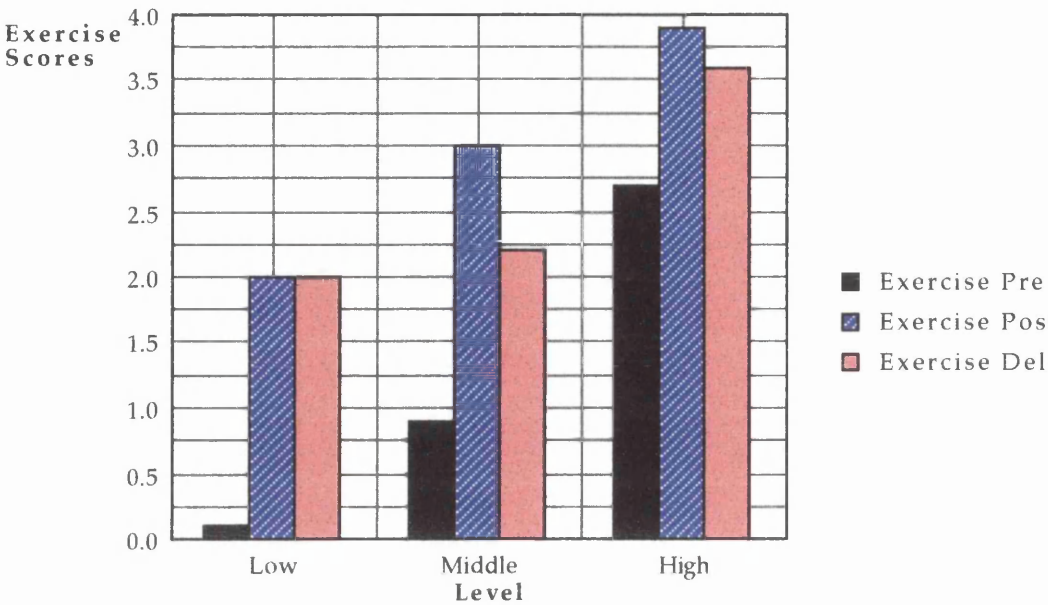


Figure 4-13
Differences in Exercise scores among students with different levels of physics background

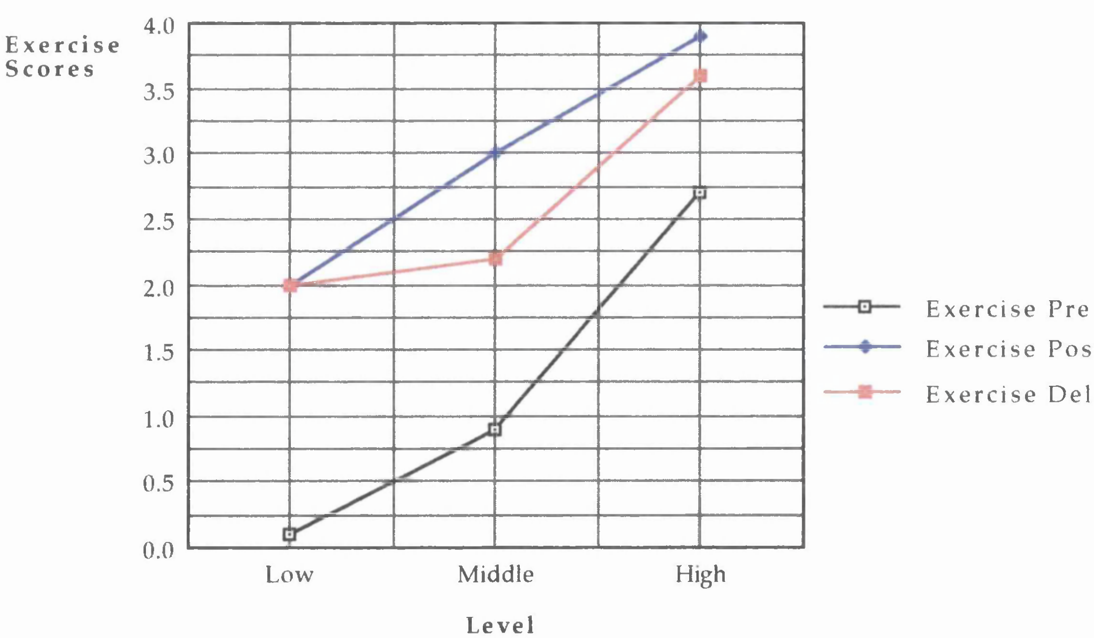


Figure 4-14
Differences in Exercise scores among students with different levels of physics background

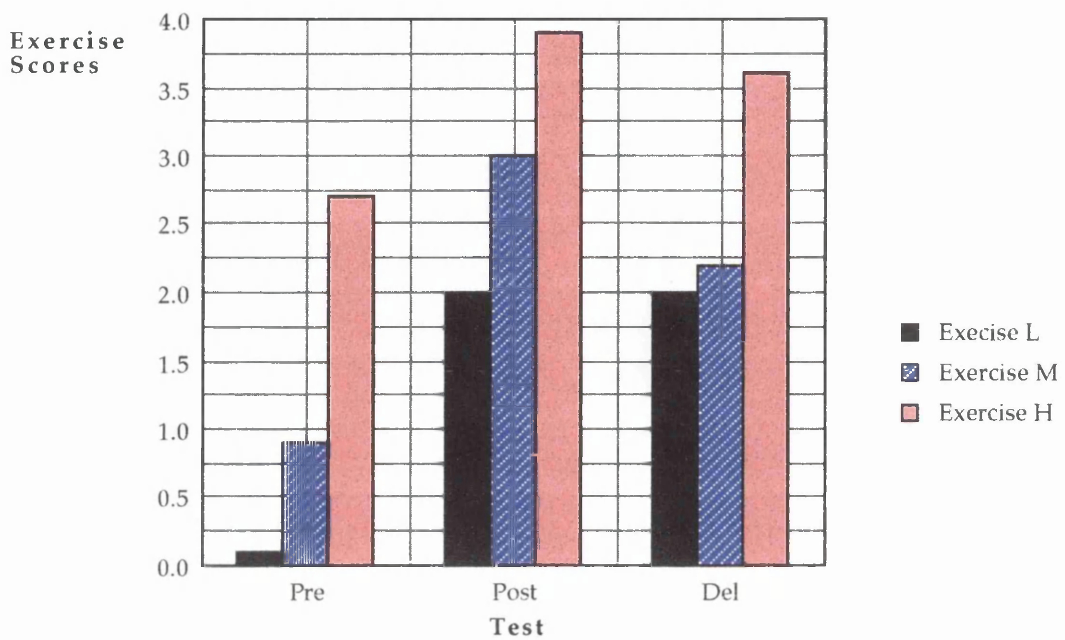


Figure 4-15
Differences in Exercise scores among students in Pre, Post and Delayed-post tests

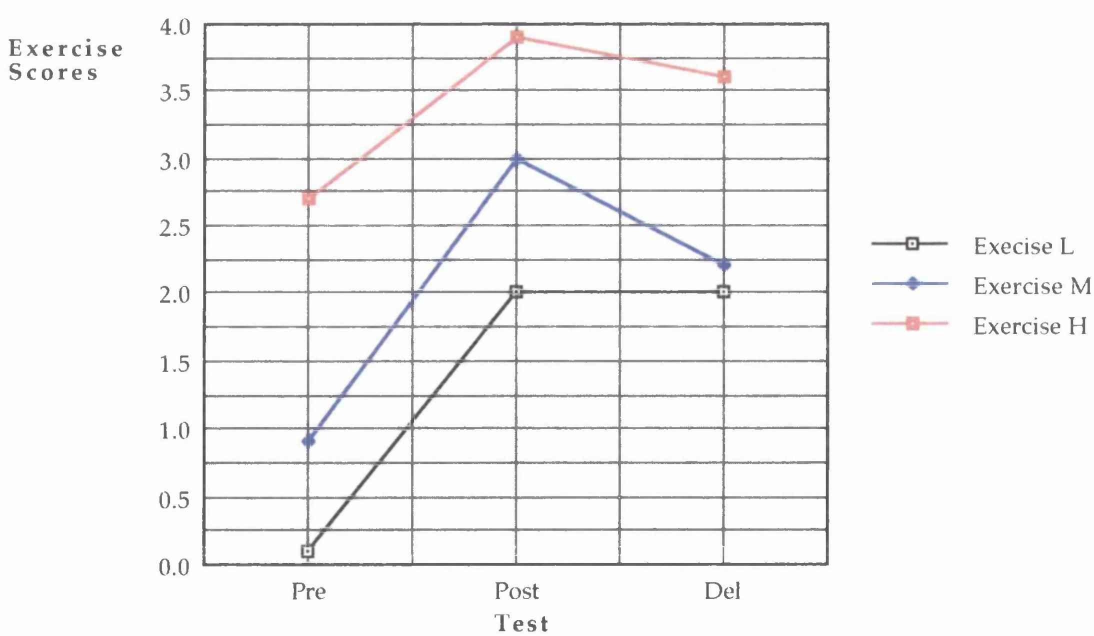


Figure 4-16
Differences in Exercise scores among students in Pre, Post and Delayed-post tests

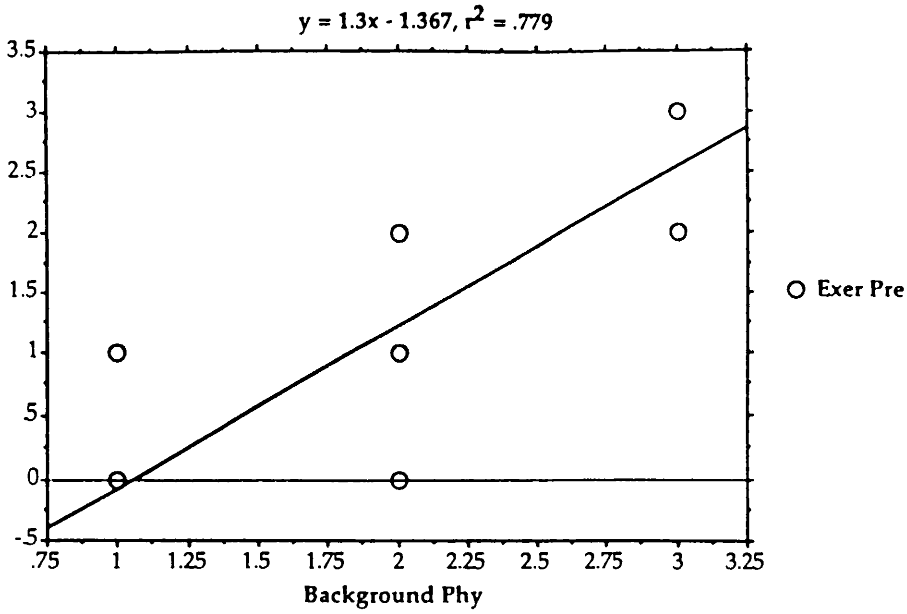


Figure 4-17
Differences in Exercise scores in the Pre test among students with different levels of physics background

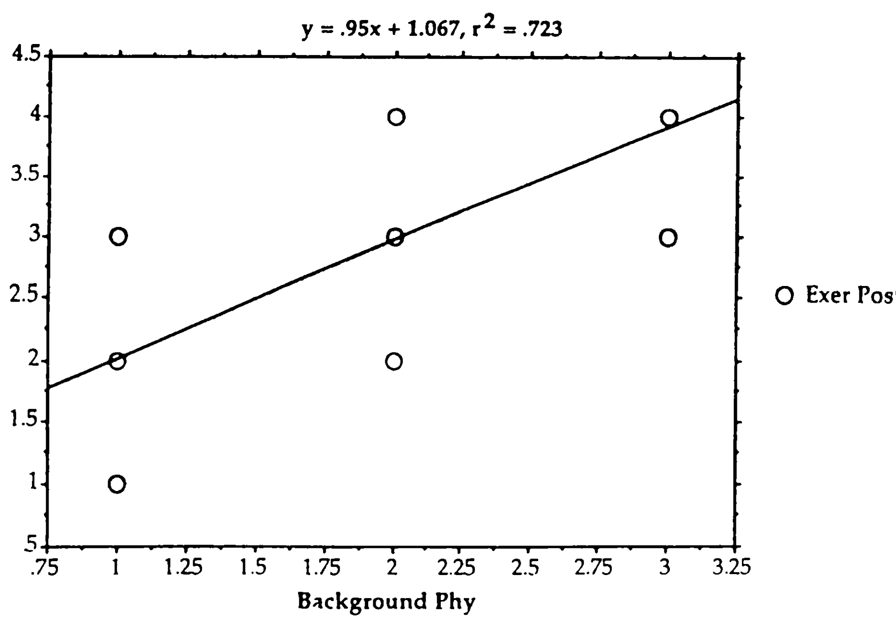


Figure 4-18
Differences in Exercise scores in the Post test among students with different levels of physics background

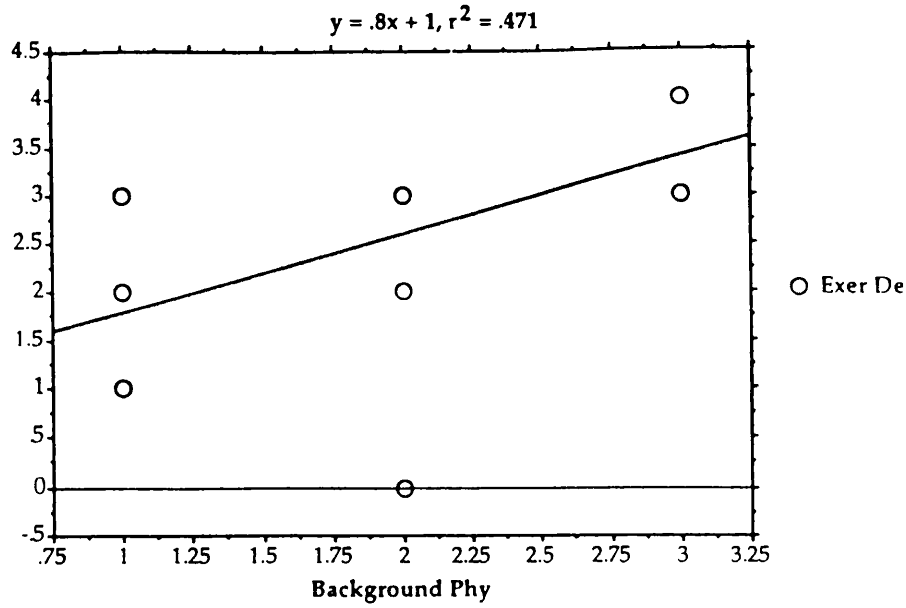


Figure 4-19

Differences in Exercise scores in the Delayed-post test among students with different levels of physics background

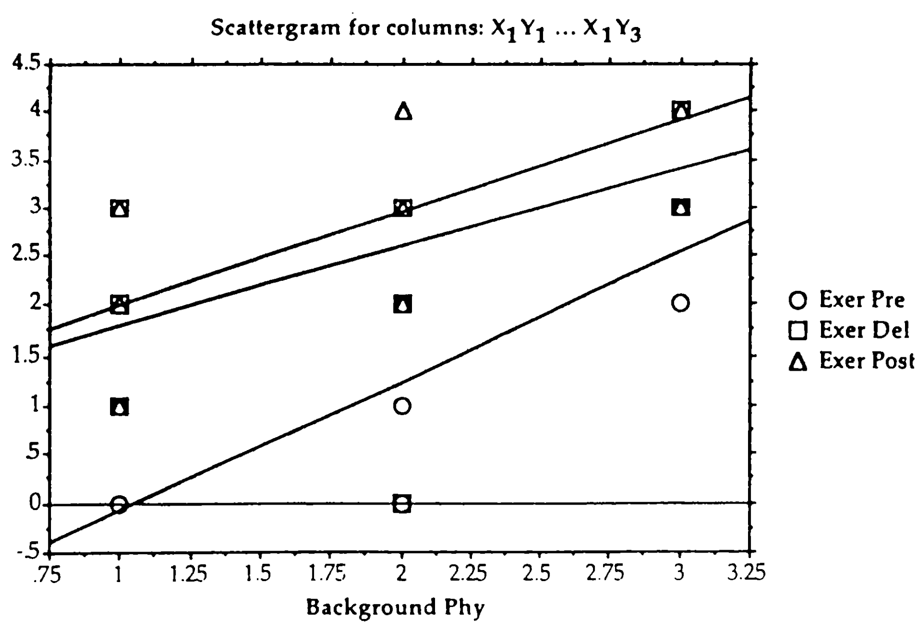
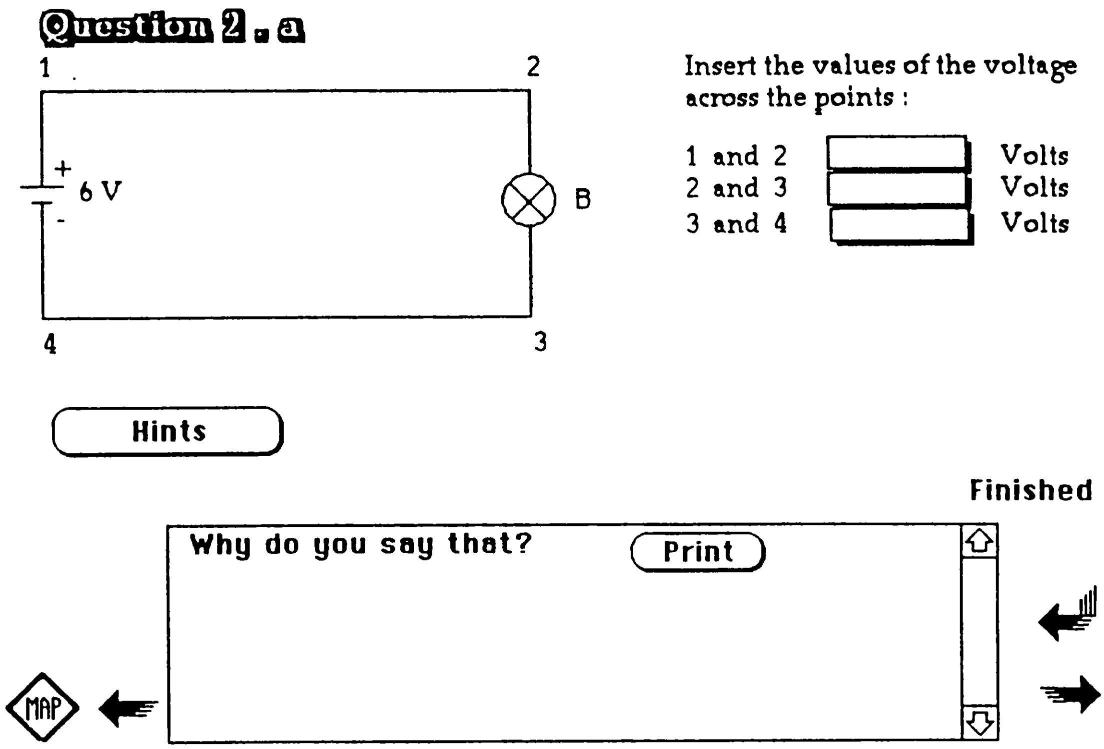


Figure 4-20

Differences in Exercise scores in the Pre, Post and Delayed-post tests among students with different levels of physics background



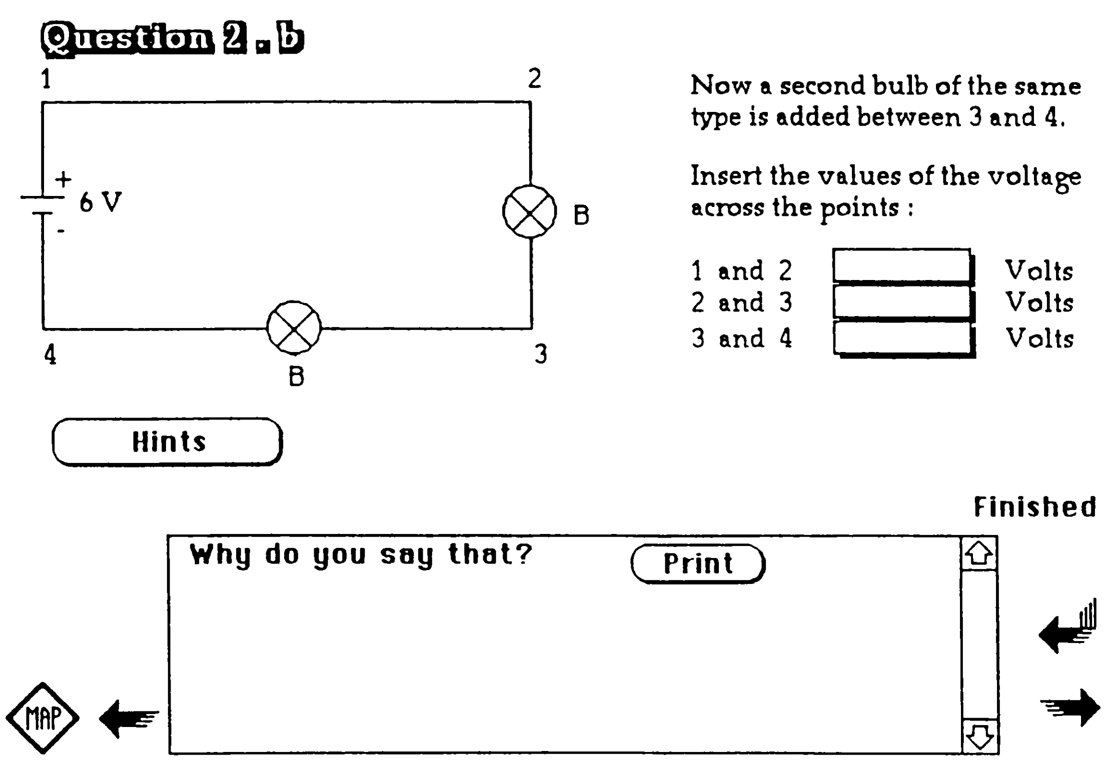
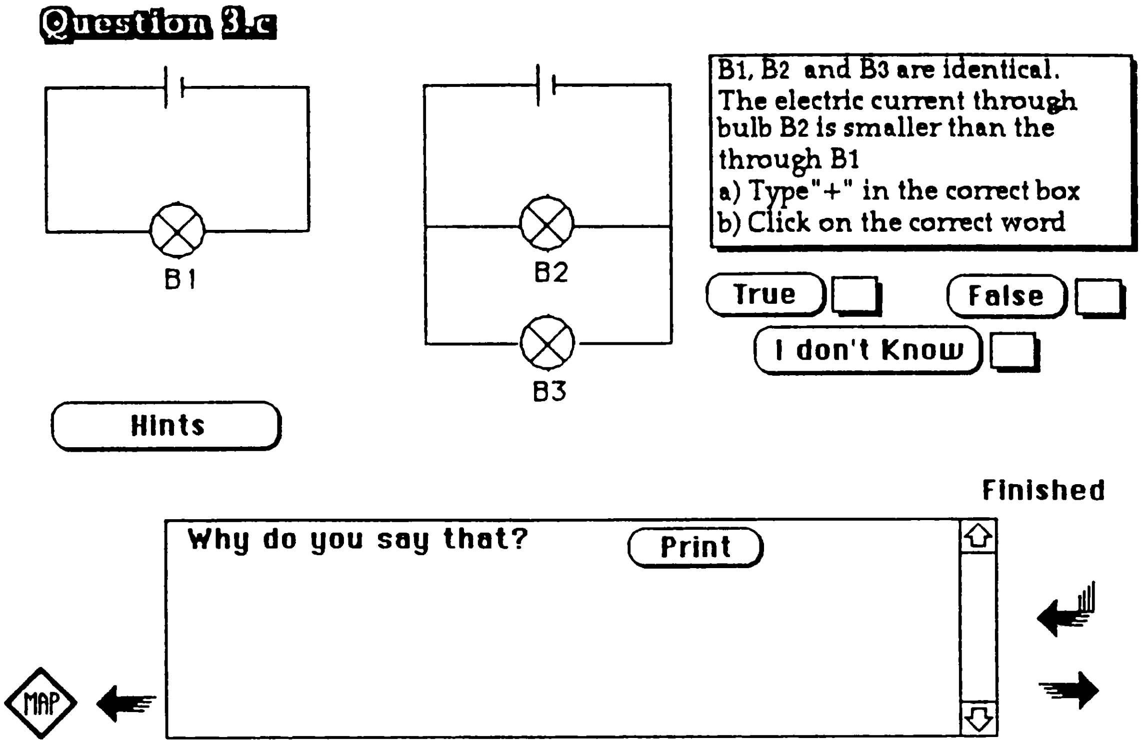


Figure 4-21
Questions 2a & 62b



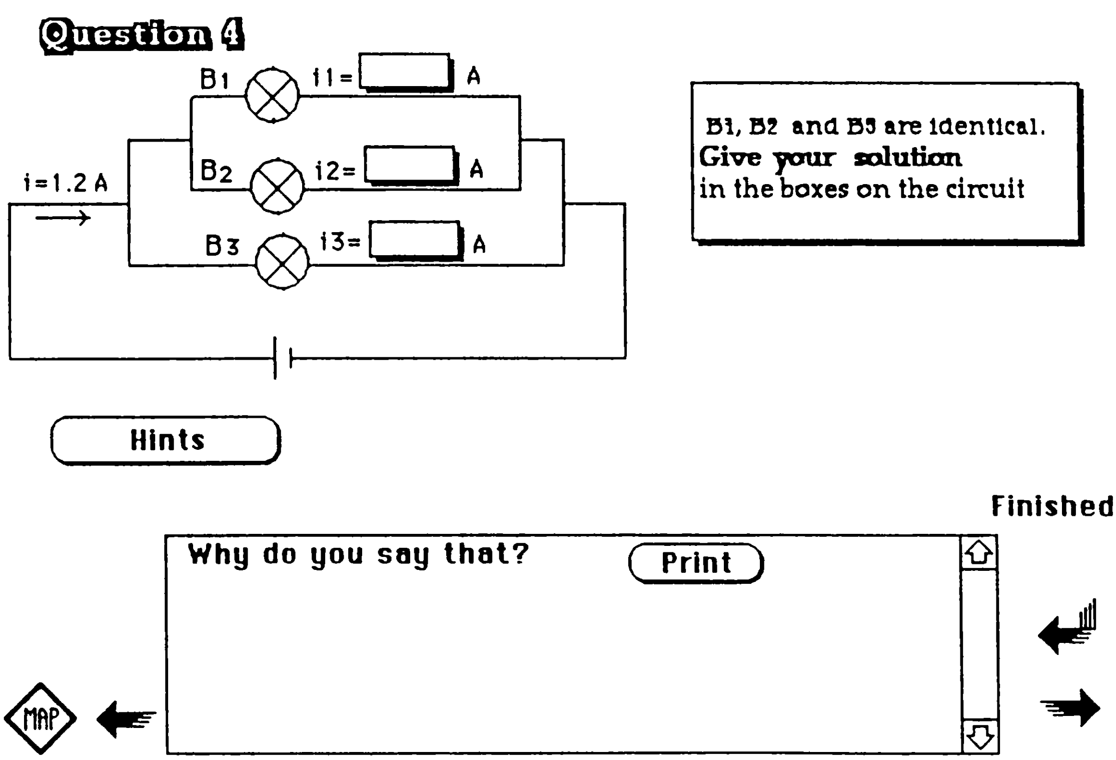
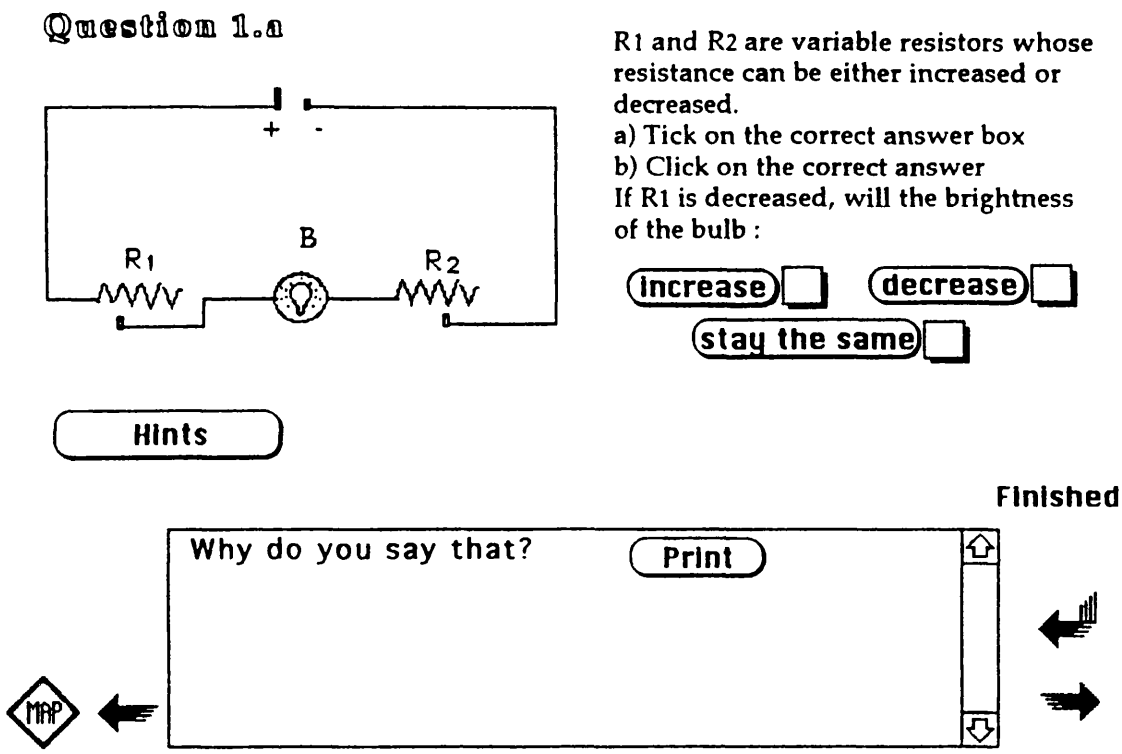


Figure 4-22
Questions 3c & 4



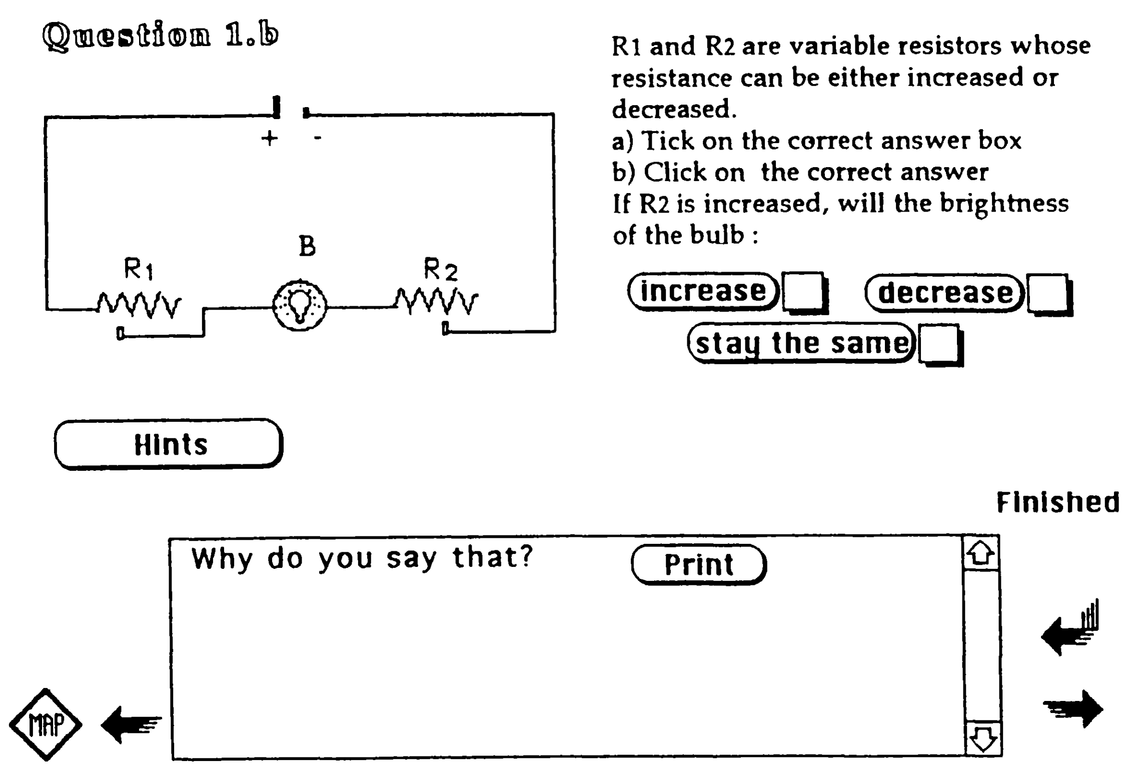
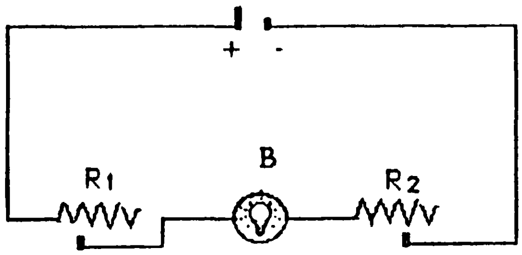


Figure 4-23
Questions 1a & 1b

Question 1.c



R1 and R2 are variable resistors whose resistance can be either increased or decreased.
a) Tick on the correct answer box
b) Click on the correct answer
If R1 is increased, will the brightness of the bulb :

increase ☐ decrease ☐
stay the same ☐

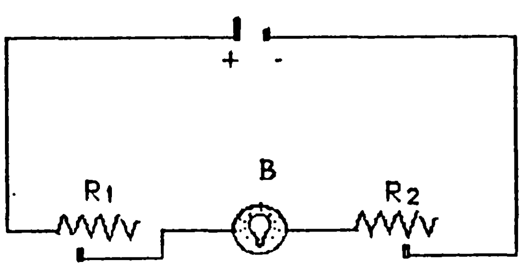
Hints

Finished

Why do you say that? Print

MAP

Question 1.d



R1 and R2 are variable resistors whose resistance can be either increased or decreased.
a) Tick on the correct answer box
b) Click on the correct answer
If R2 is decreased, will the brightness of the bulb :

increase ☐ decrease ☐
stay the same ☐

Hints

Finished

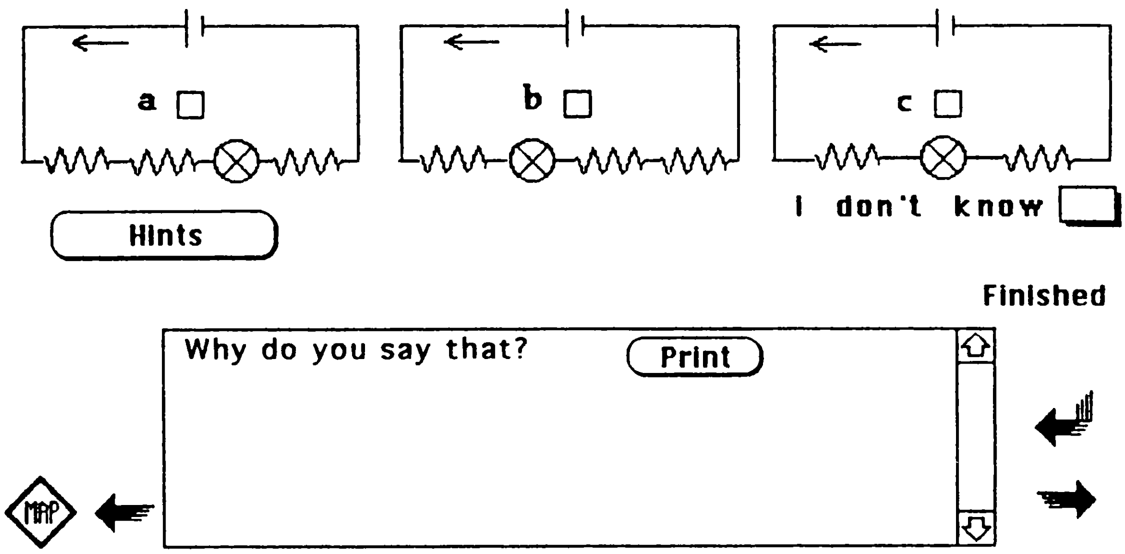
Why do you say that? Print

MAP

Figure 4-24
Questions 1c & 1d

Question 6.a

In the following set of circuits all resistors are identical. Electric current flows from positive to negative terminal, as shown by the arrows. For this set of circuits a bulb or bulbs will be brightest. If all the three bulbs would light the same brightness, then click on all three boxes.



Question 6.b

In the following set of circuits all resistors are identical. Electric current flows from positive to negative terminal, as shown by the arrows. For this set of circuits a bulb or bulbs will be brightest. If all the three bulbs would light the same brightness, then click on all three boxes.

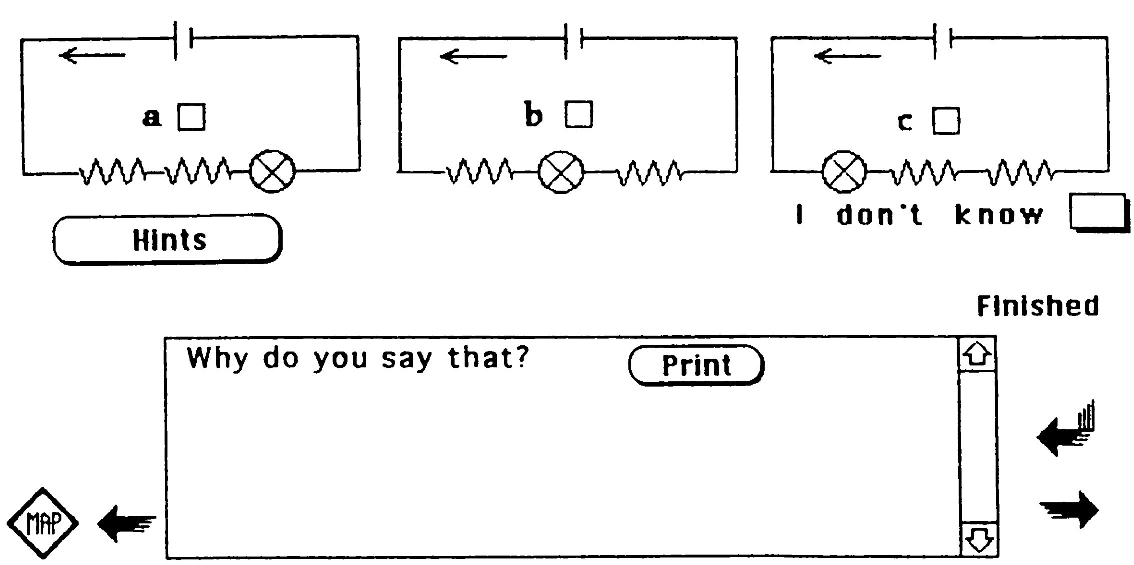
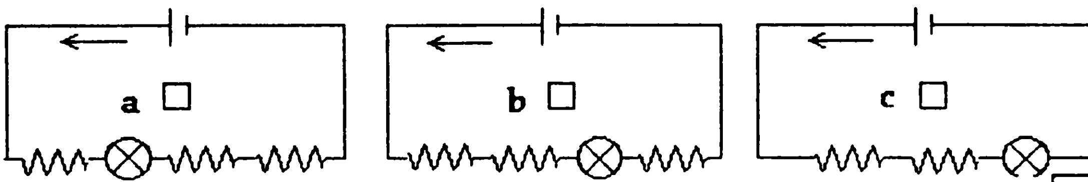


Figure 4-25
Questions 6a & 6b

Question 6.c

In the following set of circuits all resistors are identical. Electric current flows from positive to negative terminal, as shown by the arrows. For this set of circuits a bulb or bulbs will be brightest. If all the three bulbs would light the same brightness, then click on all three boxes.



I don't know

Hints

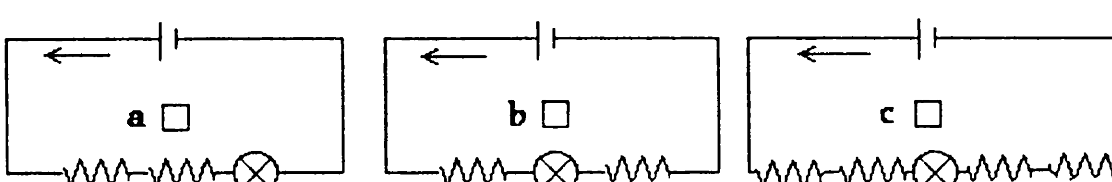
Finished

Why do you say that?

Print

Question 6.d

In the following set of circuits all resistors are identical. Electric current flows from positive to negative terminal, as shown by the arrows. For this set of circuits a bulb or bulbs will be brightest. If all the three bulbs would light the same brightness, then click on all three boxes.



I don't know

Hints

Finished

Why do you say that?

Print

Figure 4-26
Questions 6c & 6d

CHAPTER 5

CONCLUSIONS AND RECOMMENTATIONS

This chapter presents the conclusions and recommendations resulting from the research.

In conclusions, there is evidence that:

1) the software facilitated teaching and learning of electrical concepts;

2) the design principles of such an interactive computational environment could motivate students' interest, despite its simplicity.

The possibilities of providing high level text, graphics and audio design of these teaching packages were considered along with recommendations for the future of such systems in the context of Artificial Intelligence research and Educational issues.

5. 1 RESEARCH QUESTIONS

The research provided satisfactory answers to the research questions:

a) Did the software help students to understand concepts of electricity?

b) Did modelling provide a powerful learning environment?

c) Did the software help to focus on students misconceptions and incorrect models?

d) What were the students' misconceptions or their alternative frameworks for these electrical concepts?

e) What was their understanding of the concepts current i, potential difference V and resistance R, and their relationship in a circuit?

f) How effective was the software as a learning tool?

g) How much was the learning process facilitated?

The fundamental achievement of the work of this thesis was:

1) to design teaching packages using HyperCard techniques and multimedia for first year University students learning about electricity;

2) to evaluate whether these packages were a useful learning tool for understanding some electrical concepts.

The software designed in this research satisfied the following aims and perspectives:

a) To create suitable mental models for a better understanding of physics' concepts and phenomena.

b) To motivate students' learning.

c) To activate their initiative and interests for the subject taught through the high level text, graphic and audio design of these teaching packages. This design is based on students' misconceptions or alternative frameworks in learning about electricity and on HyperCard and multimedia system versatility.

d) To create an interactive and exploratory computer-based learning environment.

The type of learning environments adopted falls into the modelling category.

5. 2 RESEARCH PROJECT

5. 2 . a) FRAMEWORK OF RESEARCH

This research focused on how:

1) to activate adequate strategies to improve students' learning.

2) to create "special designed remedial activities integrated into normal classroom activities, based on a pedagogical model which took into consideration the students' preconceptions" (Picciarelli et al. 1991a).

The design of this instructional software was based on the students' persistent misunderstanding of electric current, voltage or potential difference, resistance, resistors in series and in parallel, and Ohm's law.

By using the software, students' ideas were in conflict with their own models, and were encouraged to question their model, extending or modifying it as necessary (conceptual change), so that learning took place.

Overall facilities provided by the software acted as a kind of motivational feedback and positively affected the interaction between learner and computer.

5. 2 . b) LIMITATIONS AND CONSEQUENT CONSTRAINTS ON THE RESEARCH CONCLUSIONS

As mentioned in Chapter 2 (section 2. 4. 2 p. 142), the limitations of evaluation, such as:

a) Lack of permission to collect audio/video material because of lack of the students' permission;
b) Impossibility of the presence of another independent observer being experienced in students' difficulties in the subject domain and not being within their teaching environment.
These could have limited the extension, variety and fairness of the data from interviews, think aloud techniques and observations since these data had been collected through the researcher's notes.
To verify the researcher's own interpretation of data and to increase the objectivity of the research findings, after each of the tests the data from the Pre, Post and Delay-post tests, interviews, think aloud techniques and observations were discussed and assessed not only by the researcher but also by a physics adviser from the Woodland Teacher Centre in Glasgow (see consultation, p. 293).

c) Lack of testing the software design features
The design of the Questionnaire emphasised the examination of the attitudes of the students while using the software. The Questionnaire emphasised the consequences of the use of the software on the students' reasoning and motivation for learning some electrical concepts but there were not questions on its specific design features and their relationships to learning these concepts.
In Chapter 2 Design principles from the viewpoint of learning (p.p. 92-125), the researcher has discussed how some specific visual design features of HyperCard techniques (visual style, card layout, illustrations, typography, visual and sound effects, animation) were used to create an exploratory learning environment.
However, she did not carry out experiments with these features, such as graphic screen and audio design features, so as would arise suggestions of ways to improve the visual presentation of the programme (graphic design) and therefore the learner-computer interaction (user interface).

d) Absence of written worksheets and researchers' notes and usc of partial conversation with students
In the Chapter 4, where the results of the research are discussed and analysed there are some of the students' comments and their conversations which have been selected by the researcher from a great number of their worksheets and the researcher's notes. Due to the high number of students, it became impossible for all these texts to be included. However, these can be readily provided upon request.

5.3 CONCLUSIONS

5.3.a) CONCLUSIONS FROM QUESTIONS, EXPLANATIONS AND EXERCISE

1) Students' performance

All students benefited by using the software, some more than others, because the students' performance in answering Questions, giving Explanations and doing the Exercise were increased.

2) Students' performance and their background knowledge in physics :

Questions and Explanations

a) Students at the Low level benefited more.

b) Students at the Middle level benefited less.

c) Students at the High level benefited least.

Exercise

Students of Low and Middle levels benefited more (mean scores increase 2) than those students at a High level (mean scores increase 1).

This agreed with the students' comments in the Questionnaire, in which 14 students claimed that they gained graphing skills (14 = 2H + 5M + 7L).

3) Student population homogeneity of level of understanding of electrical concepts

From Pre to Post and Delayed-post tests, a result of the above mentioned was that the students' population became more homogeneous because of the decrease of the differences on the mean scores of the Questions, Explanations and Exercise between Low & Middle, Middle & High, Low & High background levels.

The smaller the differences the greater the homogeneity concerning the levels of students' background knowledge in physics and the graphing skills, both of which had improved.

5.3.b) CONCLUSIONS FROM QUESTIONNAIRE

In their replies to the Questionnaire, the students reported that the software environment was:

1) User-friendly
The software acted as a tutor for the students in such a way that it gave positive feedback as often as possible and immediately before and after the answers to the Questions and the solution of the Exercise of the software.

2) Motivating and enjoyable
The screen layout and the structure of the software stimulated both students' intrinsic and extrinsic motivation; this in turn resulted in the development of cognitive curiosity and an increased opportunity for improved learning.

3) Exploratory
The smart illustrations and animated pictures which introduced students to another way of reasoning by linking the unfamiliar and abstract information to the familiar and concrete one.

4) "Working psychologically" towards a cognitive development
Within the software, new concepts are most efficiently learned and retained when they are linked to existing general concepts already lodged in the cognitive structure of the learner, e.g. by using models and analogies.

5) Influencing on students to achieve a meaningful understanding and other skills
A considerable number of students considered that, talking to other students and taking joint decisions on solving a problem established a better understanding of the subject domain. In addition, talking with the researcher also helped them to draw inferences on the subject domain. So, learning was an interaction with the knowledge rather than a transference of it.

In addition, the students also mentioned that they had gained computing skills on HyperCard and acquired skills in drawing graphs through the spreadsheet provided.
Finally, the students claimed that they would like to spend more time using the software to study and understand more of the theory.

5. 3. c) CONCLUSIONS
FROM QUESTIONS AND EXPLANATIONS 1&6

All the results mentioned and discussed in the previous Chapter proved:

1) Diagnosis of two types of students' sequential reasoning

This particular diagnosis proves the students' persistent misunderstandings of models of current's flow, pd., resistors and Ohm's law in series circuits.

In some Questions the research found other models of reasoning, such as local reasoning in Question 7 (short circuit) etc.

However, it is not in the scope of the research to qualitatively analyse the data of all the Questions.

Finally, within the flow aspect of current introduced by the provided causal qualitative models and analogies in both Questions 1&6, 12 out of 30 students (11 sequence model + 1 no model) adapted the system view of a circuit and they considered the role of current as a transporter of the electrical energy in a circuit.

2) Increase of the mean number of students' answers and their explanations

There was a significant increase in the mean number of the students' answers and their explanations to Questions 1&6 in the Post and Delayed-post tests.

3) Increase of the students' mean scores

There was an increase in the mean scores of the students' answers and their explanations to Questions 1&6 in the Post and Delayed-post tests.

4) Students' benefit on learning and their background knowledge

Overall, students benefited by using the software.

Students from Low and Middle level background knowledge in physics gained more benefit.

5) Software's influence on the students

Overall, students were influenced by the software.

A satisfactory number of students changed their wording while explaining their answers to Questions 1&6 because of the positive influence the software had on their thinking.

Students from a Middle and Low level background knowledge in physics were influenced by the software more than students from a High level.

6) Overcoming students' misconceptions with facilities provided by the software

The instructional software enabled students to conquer their diffuculties by confrontation with students' ideas in the post-test phase and modification of their reasoning in the post-test and delayed-post test phases.

In all stacks the view of a circuit as an interactive system appeared, so the quantities of current, pd. and resistance co-existed and correlated.
The use of models helped them to regard the flow of current as a flow of electrons and in some cases also generated their own analogies.
The software provided corrective feedback:
a) which enabled the learner to be concerned with the discovery of relationships between the unfamiliar knowledge domain and the familiar one as addressed by models and analogies;
b) which stimulated concrete, causal explanations of abstract concepts by making comparisons.
Finally, such activities joint with skilfully led discussions appeared to be an effective vehicle for conceptual restructuring so students interacted with the knowledge.

5. 4 THE CONTRIBUTION OF THE THESIS

5. 4. a) ACHIEVEMENT

1) The software helps students to understand electrical concepts
Emphasis was given to students' understanding the concepts of current i, potential difference V, resistance R, power P and their relationships in a circuit (the "system view" of a circuit).
According to the aims and perspectives of this research the software managed:

* To create suitable mental models for a better acquisition of these concepts.
* To motivate students' understanding and activate their initiative and interests for the subject taught through the designed interactive and exploratory computer-based learning environment.

a) <u>Students' performance</u>

The results of Andre and Ding's study (1991) indicated that students' performance was influenced by their background knowledge in electricity and the stimulus conditions of the experiment as well as by their misconceptions of the electrical concepts.
Similar results arose from the present research. Thus, students' performance was influenced by their background knowledge in physics and their incorrect models (misconceptions) mainly in the Pre test. In the Post and Delayed-post tests there was no such influence in Questions 1&6 and their Explanations; while for the rest of the Questions, there was either a small influence (Questions and Explanations 2, 3, 4, 5 and 7) or a great influence (Questions and Explanations 8, 9, 10).

Furthermore, the students' background knowledge, their misconceptions and the stimulus conditions of the experiment - which were the design of the software and especially the "Hints" button and the provided theoretical feedback (the Software Part 1) - influenced their performance in the Post and Delayed-post tests by increasing the number and the mean scores of students' correct answers and their explanations, because according to Andre and Ding (1991) "the stimulus conditions (of a given problem) may facilitate or inhibit retrieval of facts and principles relevant to problem solution. In some cases, the stimulus conditions may make it easy for students to find a map between their conceptual model and the real world"(p. 305) and "these stimulus conditions seem to support the subjects by providing hints by which to map a circuit conception to the components" (p. 308).

In the case of the more difficult questions, the fact that all students could not correctly and completely answer and explain, as for Questions 1&6, was due to the persistence of their misconceptions on electricity, their background knowledge and their intellectual capability.
The model possessed by the learner did relate to performance and previous experiences on the circuits. An interesting finding in Andre and Ding's study (1991, p. 312) was "the interaction between the position of difficult task and performance on the difficult and easy tasks. When the difficult task came first, performance on the difficult task was worse than when the difficult task came last". Thus, in this particular research the process of progressing from the easier to more difficult questions helped the students learn something which facilitated their performance. This also had implications on the sequencing examples in instruction provided by Software Part 1.

As in Grob, Pollak and Rhoneck's (1993) research, the test consisted of groups of two or three questions supplementary to each other with similar but not identical tasks (see section "Problems on understanding electricity: Combinations of resistors" p. 209) so that there was a successful step-by-step cognitive escalation for students' understanding of electrical concepts.

b) <u>Hints and Software Part 1 (theoretical feedback)</u>

According to Blondin (1993), the success of any learning sessions is dependent on the nature of the information gleaned by learners (what information and when) and whether training consists of problem-solving activities with the opportunity of feedback. A learner who asks for feedback is likely to benefit.
As in Grob, Pollak and Rhoneck' study (1993), the feedback given was intended to influence the way students solve similar tasks. The research findings can be interpreted as indicating that the influence of students' pre-

existing cognitive structures is more important for the process of solution than the feedback information provided in the Post test phase.

The research found prevailing positive changes in those students who developed a scientific understanding of the processes in an electric circuit in the Questions of the software, as in Grob, Pollak and Rhoneck' study (1993). Clearly positive changes were revealed in all students for Questions 1&6.

c) Improvement of learning

As in Grob, Pollak and Rhoneck' study (1993, p. 198), more students "saw" that current and voltage were proportional in the Pre test than in Post and Delayed-post tests. However, they could not comprehend the meaning of these concepts and were unable to distinguish the difference between them.

Tests showed some of the students' typical concepts. In some cases, students tried to transfer a supposedly successful strategy from one task to another. Generally, some students did not tick the answers arbitrarily, but were often uncertain as to how they arrived at an answer. This uncertainty became apparent when students had ticked the correct answer and were then asked for their reasons for doing so.

According to Grob, Pollak and Rhoneck' study (1993) since a psychological definition of learning requires positive changes and stability of correct concepts, that have already been acquired, so learning does not take place in these circumstances.

In Post and Delayed-post tests the number of students was less than in Pre test. So, an increase of stability of their correct concepts took place.

d) Consequences of the daily language for understanding the physical concepts of current

As previously mentioned in the section headed "Problems in understanding electricity: Language induced misconceptions" (p. 214), many learning difficulties are induced by daily language. It is important to bear in mind that the language that teachers use in physics instruction is responsible for further problems in understanding physics' concepts. Teachers often use inappropriate words and expressions with regard to current flow, pd. and other electrical concepts. Also physics' text books are laden with wrong lexis.

The accurate use of physical terms in the text of the software was discussed by the physics teachers and advisors from the Woodland Teacher Centre in Glasgow. It was also tested by them and by University students in the Department of E&E Engineering.

e) <u>Closer to scientific model of reasoning</u>

As in the above-mentioned, in the Post and Delayed-post tests for Questions 1&6 and their Explanations, all students correctly answered, explained and completed their questions. It was clear that over a period of five months (between Post and Delayed-post test) all of them possessed scientific model of reasoning and there was no regression of the students' ideas from this model.

Yet for the remaining Questions and their Explanations not all students were able to answer correctly and to explain correctly and completely their answers. In this case, there was a regression of their views from the scientific model because the students tended to vacillate between sequential or local reasoning and scientific model of reasoning.

However, there was a great mean increase in the mean number of students' correct answers to the remaining Questions and in students' correct Explanations to these Questions between Pre on the one hand and Post and Delayed-post tests on the other hand (65% and 84% respectively).

Similar findings are reported by Cosgrove, Osborne and Carr (1985). The researchers claimed that whilst pupils appeared to change their views after a main lesson, subsequent monitoring showed that over a period of time there was a regression of ideas away from scientific model.

2) Modelling was the software's powerful learning environment

As mentioned previously, the purpose of using models and analogies was to engage students in a process of analogical reasoning and discussion among them so that the students finally changed rather than added to their existing knowledge.

This sort of environment could provide partial solutions for learning & teaching the electrical concepts through a specially designed, computer-based, interactive and exploratory learning environment. The results were that students created suitable mental models for better understanding of the concepts, their learning was motivated, and so they activated their interests in the subject domain and enjoyed what they were studying.

a) <u>Design of software based on misconceptions and modelling for conceptual change</u>

As in Heller and Finley (1992), a conceptual change model similar to Posner, Strike, Hewson and Gertzog (1982) was used for planning a sequence of activities designed to change students' ideas about the nature of current flow. The sequence of activities was based on the introduction of two competing kinds of analogies (fluid-flow and moving-crowd). According to Sapwell

(1996) and Gentner, D. & Gentner. D. R. (1983), there are some distinct advantages in using water circuits as a preliminary approach to electrical circuits. Water is tangible and students can experiment with it. The flow is visible and pressure differences can be observed. Students can understand the conservation of water flow better than of current flow. So, the latter concept came as a consequence of the former one.

Nevertheless, two main difficulties could be overcome.
1) In circuits there was practically no feedback in reasoning. Students did not have a system view of a circuit. In their view, the pump determined the flow of water. Through the water-flow model, they better understood the conservation of the flow of water. As an insight derived from this model, they corresponded the conservation of water-flow to the conservation of current. So, the model worked.
2) There could be flow without a difference in pressure or in potential. As some students mentioned "Water flows, and that's all! To have a flow or a current all you need is a pump or a battery...", which was an actual fact.

In terms of teaching & learning, this research showed the importance of students' reasoning on electricity. There were three forms of reasoning: sequential reasoning, local reasoning and system view (constant current flow) model of reasoning .
As stated in reference books, also in this particular research, "these natural or spontaneous forms of reasoning are unavoidable steps in the learning of sciences and they probably form a hierarchy. Local reasoning is more primitive than sequential reasoning. These forms of reasoning are simpler than normative reasoning in physics and often work in a variety of every day situations... to overcome natural reasoning and to go beyond the natural hierarchy would be a guarantee of attainment of the cognitive abilities required for stable scientific knowledge. This forms what the term cognitive pathway means. Such a cognitive pathway may constitute the route of least entropy in the attainment of scientific knowledge in a domain through various models and analogies". (Closset 1993, p. 108). Also the students' misconceptions may be "a necessary stage in the cognitive pathway to expertise" (Blondin 1993, p. 127).

b) Students' junction models

The students could not "possess" the system view of a circuit. Inconsistencies were noted in their propositions on the effect of wires on current in parallel and short circuits.
Activities were designed to account for certain correct and incorrect conceptions that the students brought to instruction. For example in

Question 4, such an activity required the students to predict and explain what happens to the current at a junction of wires. Activities were also designed to help students acquire necessary knowledge about junctions and the effect of wires on current. For example, the junction activities included events to determine if the location of a junction would affect how the current divided.

Additionally, students were required to trace the current path in the actual circuit diagrams. Tracing the path of the current helped students focus on the important distinguishing features of series and parallel circuits, the presence and absence of a junction.
Moreover, tracing the current path in a series circuit helped them to recognise that the current must flow through the bulbs, so the current cannot be shared with the bulbs. In a parallel circuit the current splits and through the branch of low resistance the current is great and through the branch of high resistance the current is small.

Finally, a sequence of activities was planned to help students develop criteria for differentiating between relevant and irrelevant cues when selecting an answer to a question. A sequence of guided events was designed for the construction of some qualitative rules on what happens to the total current in the circuit and the brightness of each bulb, e.g. when a bulb is added to a circuit or is shorted or two bulbs connected in parallel are added in parallel with another bulb etc.

c) Models and analogies in concept formation

According to Aalst (1985), his observations led him to the conclusion that a teacher should be careful to connect one analogy to one group of situations and proposed that sometimes students use several analogies at the same time to explain an event or situation. Because, according to Psillos & Koumaras (1993), Wild (1996) and Sapwell (1996) analogies used in thinking have a substantial role in concept formation, in this particular study the researcher has also used more than one causal qualitative model to bridge the gap between the student's and the scientist's models for the complete and coherent image of the electrical concepts.

As found in source books and this research, students do not yet distinguish between current flow (the energy carrier) and energy changes. According to Cosgrove, Osborne and Carr (1985), and recent researchers (Psillos and Koumaras 1993, Wild 1996, Sapwell 1996) in order to tease out the difference between energy transfer in the circuit and the flow of current, useful analogies need to be introduced. Quite often more than one analogy was introduced to support understanding and to develop confidence.

In order to reconceptualise the concept of current to be scientifically acceptable, considerable preparation is needed so as to empower and entrust pieces of new knowledge, and form existing students' models. In addition to the use of analogies and models, the above mentioned approach was used.
A microscopic model of electric current was provided and given to the students. "The model could enhance sophistication in the causal account of both the function of the objects and the processes in electrical circuits. It was appealing to students because it drew on their "sense of mechanism" which has been pointed out elsewhere (diSessa 1990). The model allowed for an explanatory mechanism of the function of the battery, the resistor and their interactions in a simple electrical circuit... The two partial macroscopic models i.e. flow and energy were related through the microscopic account of the underlying processes" (Psillos and Koumaras 1993, p. 66).

Finally, it is worth mentioning that in the Delayed-post tests students used their own newly-formed models for answering and explaining their answers rather than attempting to answer and to explain by trial and error, as mentioned in Cosgrove, Osborne and Carr's (1985) study in the application phase of their research.

3) Students' misconceptions

The design of the software centred on students' misconceptions on basic concepts of electricity. It focused on both:

a) how their misunderstanding can be diagnosed by themselves and the researcher/teacher

b) how to change their ideas

by providing a methodology for confronting their misconceptions or alternative frameworks.
In addition, further evidence for the widespread nature of fundamental misconceptions was produced.

Finally, the software also showed that modelling provides partial solutions to learning & teaching electricity, and outlined some ways in which such work might be developed in order to provide powerful learning environments (See in later section headed Recommendations p. 308)

As per the findings of Mc Dermott and van Zee (1985, p. p. 44 - 47), this research also pointed out the following difficulties experienced by students:

a) <u>To "possess" an adequate model for current flow</u>

Many students thought that the same amount of current was supplied by a battery/pd. to all circuits. Current was "used up" while flowing through the

resistors and bulbs. These students considered that the direction of current flow was essential, because it regulated the order that current flowed through certain resistors or bulbs.
To correctly predict the relative brightness of a bulb, it is advantageous to "possess" the scientist's model of current, in which current is not "used up" as it flows through resistors and bulbs but varies with the total resistance in the circuit.

b) <u>To discriminate between related concepts</u>

Discussing their predictions the students frequently mentioned the terms current, energy, power, and pd. or voltage. However, some of them did not know the use of the appropriate term in a given situation. They often changed the terms for another one or merely mentioned them.

c) <u>To understand the function of various elements in a circuit</u>

Many students misunderstood the main and basic functions of elements in simple circuits; e.g. these students generally viewed the battery as a supplier of current instead of a source of constant pd./voltage.

d) <u>To apply formalism</u>

* <u>to electric circuits</u>

Many students could remember formulae involving power P, resistance R, intensity of current i, and potential difference V. However, often they could not relate the results of their calculations or even the quantities represented by these symbols, to circuits. Also they could not translate between circuit diagrams and the quantities represented by these symbols in the circuits.

* <u>in written solutions of circuit problems</u>

When the students were asked to order the brightness of bulbs in circuits, many of them calculated and compared the power dissipated by bulbs. This order was dependent on which of the formulae for power these students applied and whether the quantities were applied to the whole circuit or each one of the bulbs.

5. 4. b) IMPORTANCE OF THE RESEARCH

For the learner

Students worked in a interactive and exploratory learning environment. While using the software, they developed:

a) <u>Independent learning based on the students' self-confidence</u>

Students worked according to their level, needs and requirements.
Individuals with different levels of experience need different levels of instructional support in order to make sense of and profit from instruction in physics. Traditional courses have not provided such a differential support.

Many students are likely not to do well in physics and to find physics uninteresting because the course does not adapt itself to their conceptual needs, while computer-based teaching & learning could provide customised support (suitable software), as also Doughty et al. (1997) claimed.
In their Questionnaires, the students commented on the software being interesting because of the motivational environment and feedback provided. Students could work at a pace in line with their own level, needs and requirements.

b) Cognitive strategies, qualitative problem-solving skills

Many researchers, such as Cosgrove, Osborne & Carr (1985) and Unruch et al. (1997), claimed that the proficient physicist attempts to think about a problem qualitatively, to develop a feeling for the problem qualitatively to see if it makes sense, otherwise s/he re-organises and re-structures the information (sketches, flow diagrams etc. are commonly made). Then s/he proceeds to select a suitable formula.
In the Post test phase of the research, qualitative reasoning was the process of shuffling students' concepts about in order to bring them to think about particular problems. Thus, qualitative problem-solving was considered as an important skill that students developed as an explicit part of school physics.

For the teacher

a) Planning of instruction for substantial change of understanding

The results of this study provided an extensive and precise basis for the detailed planning of instruction. The researcher's opinion is that the knowledge she gained from analysing the sources of variability in performance on problem-solving in the Pre test phase was valuable in developing instruction and in the insights provided because they could be employed as she interacted with students during the Post test phase. This opinion is supported by the students' reactions to the instruction and by the analyses of the results of the Post and Delayed-post tests. There were substantial changes in students' understanding of current electricity, and they became more capable of answering and explaining their answers on what actually happens to the total current in a circuit and the brightness of bulbs in various circuits.

b) Change of the traditional role of teacher

As previously mentioned in recent years Educational Technology has changed the traditional role of the teacher in a class (Watkins, Augusti and Calverley 1997). Microcomputers accompanied by other media are powerful tools for the teacher, who acts as a "clarifier of ideas" and as a "facilitator" to the acquisition of knowledge. He/she is also "a model of scientific thinking" for students. In his/her role, the teacher becomes "an adversary in the sense of a Socratic tutor" so as to help students to accommodate new concepts.

c) <u>Effective distribution of work</u>

The teacher has a remedial tool which has been designed for various levels of students' knowledge, which helps to discover certain misconceptions or alternative frameworks of his/her students and provides more concrete assistance if, when and where it is needed. This means that in the first phase, students can help themselves by using the feedback provided by the software. So, the teacher's help is mainly focused on certain groups of students with particular difficulties (Doughty et al. 1997, Watkins, Augusti and Calverley 1997). A more effective distribution of work takes place not only for the teacher but also for students.

Consequently, a pleasant learning atmosphere is created for effective classroom interaction.

For the designer

The results of the evaluation of the described software might be a framework for an integrated design of effective, educational software. Bearing in mind students' and teachers' needs and requirements and, as a professional in this field s/he can contribute a high level text, graphic and audio design (See further details of this in the later section of Recommendations).

5. 5 WIDER ISSUES FROM THE RESEARCH

The research on electric current and its behaviour in circuits tends to confirm the difficulties of changing students' ideas towards the views of scientists.

The researcher was encouraged by the way that the students were prepared to discuss their views, to "listen" to others' views, to attempt to relate their own ideas to the evidence provided by the software and to the various analogies which they learned about. All these activities are valuable whether or not the model of electric current that students find sensible and useful is finally the scientist's view. Nevertheless, this issue raises the need for more debate and research concerning the use of models and analogies for learning about electricity.

As in much educational research, there is also an increasing awareness that conceptual change takes time and that it is important that counter-intuitive ideas are reconsidered at regular intervals over a period of time. This has implications on the curriculum.

Finally, the research reconfirms the essential importance of students' comprehension of basic electric concepts for on-going learning about electricity. Without the scientific view of current the development of more advanced scientific concepts associated with circuitry is problematic.
In his book "Mindstorms: Children, computer and powerful ideas", Seymour Papert (1980) presented the use of computer models as a microworld, where a single idea is demonstrated by the computer model, thus isolating the concept from complex surroundings or side-effects to make it easier for students to focus on, and thus understand, the concept.
From this research, it seems to be possible to adapt Papert's idea to the electric circuit, particularly with regards to the system approach. Computer programmes therefore are proposed as a medium to support teaching & learning electricity by using fewer words - verbosity tends to be the cause of students' misconceptions - and yet leads students to better concentration on essential points.

5. 6 RECOMMENDATIONS

1) More time for students' work on software in full courses

In the Questionnaire, 67% of students claimed that they would like to spend more time using the software to study and understand more of the theory. Furthermore, one student suggested that the software would be more useful if the presentation on the electrical concepts was given in shorter sessions. Researchers, such as Atkinson (1978), Parker & Lepper (1992), Doughty et al. (1997) and Unruch et al. (1997), stressed that the length of the time students devoted to work on these sorts of learning & teaching packages, have a great bearing on the outcome of their learning process.

Consequently, as A. Bork (1993) also claimed in his article, it is recommended from the research that this kind of computer packages should be developed in full courses so that students could spend more time on them.

2) Software for all students' needs and requirements

The main disadvantage of the instructional software was the fact that the students from a Low level and Middle level of background knowledge in physics benefited more. It could not meet the requirements and needs of the High level students. The design of such software requires a co-operative work of groups of designers, expert in different disciplines, as mentioned later in this Chapter.

3) Influence of the software on students' cognitive behaviour

Because of the influence of the software on their thinking, a large number of students changed their wording while explaining their answers to Questions 1&6. As mentioned previously :
In Question 1,
there were 8 out of 30 students (27%) [8 students=3L+4M+1H]
and in Question 6,
there were 11 out of 30 students (37%) [11 students=5L+5M+1H].
It is clear from the research findings that students from Middle and Low level background knowledge in physics were influenced more than students of High level.
Further more, detailed research is needed with a larger number of students taking part in it to see how their cognitive behaviour (i.e. change of wording) is influenced by the software.

4) Software improvements to enable deeper understanding

To improve learning several changes need to be adopted:

* a change to more extended sequence of questions (interposing additional questions and exercises, and combination of these variations)
* a summary of the basic concepts and important rules in electricity

By using the software, the limited objective was to train students on how to apply electrical concepts of rules in learning sequences for groups of similar questions; e.g. Questions 1, 6 and 8. These activities introduced further discussion which is aimed at conceptual changes, Grob, Pollak and Rhoneck (1993) also claimed in their study.

a) Improving students performance in specific domains

The initiation of learning processes on a broad scale was not achieved. further research should be done towards improving students performance in specific domains such as changes in resistors in parallel, in mixed - series and parallel - and more complicated connections.

b) Increase on the number of questions and exercises

Overall, the research suggests an increase in the number of questions and a greater sequence of questions, so that a gradual cognitive escalation occurs among the questions which can be developed step-by-step from low to high level of difficulty.
As mentioned in the previous Chapter (p. 209 Combinations of resistors, p. 247 Delayed-post test phase: Metacognition), e.g. Question 8 was

supplementary to Questions 1&6, but an advanced level of reasoning was required for it to be answered and explained completely.
Furthermore, additional exercises must be interposed with the aim of using spreadsheets and diagrams so that students can draw inferences on the relationships between variables, such as i, V, R and P, in circuits.

c) Tracing the path of the current and simplifying multiple junctions in circuits

In addition, tracing the path of the current helped students to grasp the important distinguishing characteristics of series and parallel circuits, the presence and absence of a junction.
Drawing equivalent circuits, which were more simple than the original circuits, also helped them to conceive the main features of series, parallel and mixed circuits and overall to simplify multiple junctions in circuits.
Both the above mentioned techniques were introduced by the researcher during discussion with students, so as to help them understand relevant topics on electricity. So, it is recommended that for the next design of instructional software both tracing the path of current and the sequence of equivalent, simplified circuits could be provided in the form of animated pictures and simulations.

d) Advanced level design

With reference to research findings (Bork 1993) in order to reconceptualise the basic concepts and important rules in electricity requires an advanced level of text and audio design by teams with expertise in the area in Artificial Intelligence and Expert Systems (See later section p. 312).

5) Development of students' qualitative problem-solving skills

As was observed in the Post test phase of the research and in agreement with recent educational researchers, qualitative reasoning consisted of re-ordering students' concepts in order to bring them to consider a particular problem.
In this research, it seems that qualitative problem-solving was considered as an one of the important skills that students could develop, even as an explicit part of school physics.
Therefore, it can also be included within the framework of the design of educational computer packages. Furthermore, such a skill need not be dependent upon mathematical skills and techniques, therefore it could be developed at a relatively young age, after a suitable curriculum design.

6) Curriculum accompanied by textbooks and computer based material to address students' difficulties

As has been proposed by researchers, such as McDermott and van Zee (1985) and Bork (1993), emphasis must be placed on developing a model which enables students to predict the relative brightness of bulbs in various configurations through specially designed instructional materials, textbooks and computer packages within the framework of a suitable curriculum design.

This type of material enabled students to construct a qualitative model in analysing various circuits. Explaining the discrepancies with their predictions (answers to Questions), while also using the software, the students could confront and resolve their misconceptions, such as those discussed earlier.

Findings of the present research can be used to enhance the development of conceptual clarity.

As Bork (1993, p. 346) pointed out "small amounts of interactive material will lead to only minor changes and small changes will lead to small differences. A full course and curriculum development is essential... We can only realise the full potential of the new interactive technologies if we rebuild our courses, assuming the use of technology from the beginning".

7) Implications on teaching and learning

The implications on teaching and learning seem to be the following:

a) Proceed more carefully and slowly in teaching & learning simple series and parallel circuits;

b) Focus on simple functional contexts of both series and parallel circuits. These contexts have to be relevant to students;

c) In particular use of diagrams should be aimed at Engineering and Science students and a certain plan is required to help the students learn these skills;

d) Physics teaching should help students to evaluate verbal arguments and show situations in which qualitative reasoning gives better answers than merely a manipulation of numbers.

8) Further improvements of the software

Up to this point, the research undertaken with the students has suggested that the instructional software did not only act as a simple diagnostic tool for students' misconceptions but also helped students "to help themselves through self-monitoring or tutoring of their self-control activities" (Linard 1995, p. 241). "Appropriateness" for educational software "lies in the quality of the help to (students') self-help ... rather than directly controlling their behaviour", as mentioned in Linard's article. In such a design, the knowledge and the experience of professionals in the area of Artificial Intelligence and Expert Systems is required. There is a short overview in Chapter 2 (p.p. 104-124) and in a later section of this Chapter for A.I., Expert systems and recent knowledge based technology.

Based on this research, the following points are recommended:

Firstly, as in Boohan's diagnostic programme (1993) the comments, which appeared on screen, should summarise the "model" that students possessed as well as categorise students' misunderstandings.

Secondly, based on the students' model, the teacher can provide activities (questions and exercises) addressing the students' needs and requirements.

Additionally, the researcher/teacher can use discussions with students basing them on specific errors. Therefore, conversation - whether face-to-face or technology mediated - becomes the best way for teachers and students to elicit discrepancies between their respective knowledge and to establish the appropriate means to bridge the gap, according to Laurillard's conversational model (1993).

9) Recommendations for designers

a) <u>Working in teams of experts in various disciplines</u>

The results of the evaluation of the described software might be a framework for an integrated design of effective and educational software. Bearing in mind students' and teachers' needs and requirements and as a professional in this field the designer can contribute high level text, graphic and audio design.

Computer programmes have also been used to promote conceptual change. For example, the use of simulation programmes, e. g. Crocodile Clips in circuits, and other Expert Systems have been used in science education. Nevertheless, the underlying models are those of the expert, and so the explanations delivered by the systems are only based on expert models of the domain which differ to the students' models. According to Loureiro (1993, p. 262-265) the use of such systems results in students becoming "lost" because they are not experienced in the domain.

In order to overcome this problem "either the teacher/researcher has to intervene or the system has to be able to follow what the student is doing and to help him/her".

Additionally, as it appears in the literature, the use of teacher led discussions on the meaning of concepts and on their relations seems to be of benefit to students' learning.

The development of such systems requires experts from several disciplines. Choosing the right people for the software design is a crucial and decisive step in the production of appropriate educational software.

For example, most of the authors for the Scientific Reasoning Series (Bork 1993) were not only computer experts but excellent also scientists and teachers who work in groups. Attention was paid to finding teachers with special qualifications and talents, namely teachers that:

1) Had spent time individually with students
2) Had considered the learning difficulties:

 to recognise the occurrence of these difficulties and

 to assist students with difficulties.

As a result, these qualities ensured the material could be tailored to students' needs.

"It is the insights of very good teachers that are the most critical ingredient in producing high quality learning material" (Bork 1993, p. 340).

As in Boohan's article (1993, p. 194) it is recommended by the present research that the Questions provided by the software could make reasonable diagnoses of students' misunderstandings.

Therefore, "a key issue is the extent to which it will be possible using research findings in these areas and the experience of teachers all around the world to write questionnaires which are both useful and not too time-consuming to produce. If this proves possible then there could be a wide use for this kind of diagnostic programmes in appropriate educational computer packages".

Many types of people can also be involved in the design groups. These are:

1) people who have experience in research within the areas of the naive theories that students have in science.
2) people who have designed such material before and have had enough experience with human-computer interaction

For instance, a computer-based aptitude test for electrical engineering students (Pudlowski and Rados 1994) was a co-operative design from an international team of experts. This team consisted of scientists from the University of Sydney, Australia, the University of Cracow, Poland, and the University of Cape Town South Africa. Similar work has been done by other design groups from other universities and research centres in the same country, as in the following examples: simulation of electric circuits with an electronic spreadsheet (Alberto Silva 1994), teaching Newtonian Physics in a HyperCard based environment (Gill and Wright 1994), evaluation of a Physics multimedia resource (Watkins et al., SToMP Project, 1995) and many others (Draper et al. 1996, Doughty et al. 1997). All the above-mentioned research has already been discussed in the Introduction Chapter 1.

b) Artificial Intelligence Technology in educational applications

As mentioned in Chapter 2, recent developments in educational and cognitive learning theory have been adopted by developers of knowledge-based computer learning systems. Their focus is on Artificial Intelligence Technology which has been applied to educational applications in the last few years.

Hypertext and Hypermedia systems are branching systems that allow the sequence in which material is accessed to be decided by the student. However, there is no control over where the student goes; this can cause impaired learning.

One way to avoid the complexities of such systems is to have the student volunteer the necessary knowledge to the teacher rather than needing the tutor to infer it. In this way, the student has a greater control over the learning session.

Research along these lines has been conducted under the heading of "guided discovery tutoring" (Elsom-Cook 1990) and "knowledge negotiation" (Moyse et al. 1992). Related work in "case-based teaching" (Schank, 1991) and "hypermedia browsing systems" (Nix and Spiro 1990) has addressed the problem of limiting intervention by the teacher while still maintaining a sense of didactic relevance in the opportunities given to students to direct their own learning. Also "intelligent critics" (Silverman 1992) addresses issues relevant to guided discovery.

In their paper, Khan and Yip (1996) outline the motivation for case-based learning systems. Research has had on the development of their own work on "partial self-directed learning", which is based on case-based reasoning (CBR) techniques.

The researchers consider the various ways in which CBR may be used to improve certain functions of ICAL systems and 14 pedagogic principles that have contributed to the development of CBR systems are proposed in the near future.

c) Another view of learning as a human knowledge activity in its own right

According to (George 1983), "as a process of self- and world-adaptive transformation, learning is just one complex kind of deliberate activity among others, with specific addition of systematicity, reflexivity, symbolic abstractedness and wilful personal change to the ordinary aspects of action".

The learner selects certain pieces of essential information and links them by causal relationships in order to answer various questions.

For the Questions of the software and especially for the "Why do you say that" question, students needed to use cognitive strategies of selecting, comparing, inferring, arranging and revising (Rein and Schon 1977, Bennett 1978, Robinson and Hawpe 1986).

From research in the use of hypertext Dillon et al. (1990), Hammond and Allinson (1987 & 1989), McAleese (1989) pointed out that the navigational metaphor (free browsing) is seen as an expression of human action and learning.

Practising with the hypertext, certain difficulties have also been reported. These typically derive from users' navigation and are mostly related to the control processes of action, which mainly rely on memory representations. In hypertext, the segmentation of information is networked, multilayered and nested. This segmentation makes the comprehension of the general structure particularly difficult to retain, and demands the students' use of memorising. As a result, the above-mentioned constitute the main disadvantage in the hypertextual usage. Also expressions such as "getting lost in the hyperspace" and "cognitive overload" are often included in users' complaints.

As in Linard (1995, p. 248), Leontiev (1978) argued that "people behave differently to situations of frustration at the different levels: from nearly automatic, effortless adaptation when only actual, familiar situational conditions are changed, to conscious effort with more or less emotional stress in the setting a new goal when a goal is frustrated, onto emotional upset, distress and unpredictable behaviour when a motive is frustrated".

Difficulties in navigating can be advantageous in the learning activity. As mentioned previously in Chapter 2, people assimilate knowledge through symbolic representation. A crucial aspect of knowledge assimilation is in the activity required to gain the knowledge. This activity enables people to transform outer information into their inner personal knowledge. As a result, people need to spend time and make effort to assimilate knowledge.

Thus, "the navigational metaphor which cropped up with hypertext usage remains as one of the most enlightening, comprehensive images of the specific features of human learning as a dynamic, situated journey bristling with obstacles and hazardous encounters" (Linard 1995, p. 248).

As Hacker (1986) concluded from experimental evidence "men never bear load passively" because they rather anticipate cognitive load and try to modify their goals and strategies so that they deal with it, or better still remove it.

Many other cognitive technologies seem to ignore how human knowledge is developed. "Computer people" rather neglect the differences between human and machine intelligence when conceiving and designing systems from the viewpoint of experts. Norman (1988 & 1993) pointed out that computer software often requires the cognitive understanding and effort from "non-computer" people, and where the rational or paradigm is not clear this creates frustration and guilt. "In particular, that information cannot be equated with personal knowledge, nor computing with intentional action, nor task- with goal-setting, nor browsing with learning" (Linard 1995, p. 250). From personal self-training and teaching experience on I. T, the more intelligent the systems are, the more problematic their use become.

Keeping in line with Laurillard's (1993) focus, a "conversational model" of teaching & learning is suggested rather to support the passage to conceptual knowledge and formal thinking in Piagetian terms, that is, the access to abstract principles and laws.
In conclusion, "the support of learning through media will increasingly have to include a mediation of learner's dynamic course of action, all the way from perception of objective data to production of subjective knowing" (Linard 1995, p. 251).

5. 7 FINAL REMARKS

As mentioned in Chapter 2, learning is conceived to be exclusively dependent on studying activities (see Fig. 2-1 Prerequisites of learning) which in turn are dependent on the following groups of factors:
Prior knowledge, intellectual capability, environmental factors, motivation and learning strategies. The first two groups of factors are directly related to the learner. The rest of them are the focus of the design of the instructional software taking into account students' alternative frameworks (misconceptions) in the area of electricity. These also have different and varying influences on each student. The amount of influence often varies with the same student due to the fact that the student can be in different situations or learning conditions.

The software design was very simple because it was created by a researcher, who is a teacher of physics with experience in the difficulties students face in electrical concepts and with only a short self-training on HyperCard techniques and multimedia.

As already been referred to Chapter 2, the use of such software as a knowledge-based system offered something new and important to knowledge acquisition :

a) Students' manipulation and insights of different ways in which the knowledge in Electricity can be acquired;
b) Students' concentration on electrical concepts;
c) Increase of students' cognitive activity;
d) Self-detection of their errors and mistakes;
e) Debugging of their own knowledge;
f) Increase of the chances for long term retention;

The research findings suggest that the interactive use of computers can be of major value in science education because the effectiveness of this kind of interactive technology was demonstrated on difficult topics to learn, such as electrical concepts.
This kind of interactive technology :

a) makes learning more interactive and more individualised;
b) stresses thought processes so that students move away from memory-based learning electricity;
c) provides individualisation and mastery of learning;
d) maintains students' interest;
e) can be used everywhere and whenever needed.

The results of the research suggest that the use of a highly interactive well-designed computer-based learning material could have a major impact on improving physics education. Full course and curriculum development (far more material of this kind) is essential, as also Bork (1993), McDermott and van Zee (1985) and other researchers also claimed.

The computer accompanied with the relevant technology is a new learning medium and provides extremely powerful learning capabilities at reasonable cost. Interactive computer dialogues enables one teacher to work with a small group of students. As a result, they can be more active learners. Learning varies with each student and depends on his/her responses in the student-computer interaction, so the information can be individualised due to the needs of each student. Containing segments from many media, the computer packages can increase learning capabilities.

Computer-based learning packages are not the equivalent of a Socrates for each student. However, highly interactive software developed by teachers, who are selected from all over the world because of their skills to assist students' learning, can be superior to economically possible learning situations. Also as mentioned in Chapter 2, this software can stimulate the intrinsic motivation to learn and enables students to obtain highly individualised learning tasks.

Nevertheless, according to Lepper et al. (1993) effective CAL requires not only good software, but mainly teachers who introduce computers to their students as a learning & teaching tool.

APPENDIX I

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	2024.489	69.81	.75	.7993
Within subjects	60	5581.333	93.022		
treatments	2	4379.756	2189.878	105.705	.0001
residual	58	1201.578	20.717		
Total	89	7605.822			

Reliability Estimates for- All treatments: -.333 Single Treatment: -.091

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Q Tot Pre	30	42.1	9.492	1.733
Q Tot Post	30	57.267	3.084	.563
Q Tot Del	30	56.5	3.411	.623

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Q Tot Pre vs. Q Tot Post	-15.167	2.352*	83.276*	12.905
Q Tot Pre vs. Q Tot Del	-14.4	2.352*	75.069*	12.253
Q Tot Post vs. Q Tot Del	.767	2.352	.213	.652

* Significant at 95%

Table A-1
Statistical results of Questions (ANOVA - test)

Wilcoxon signed-rank X 1 : Q Tot Pre Y 1 : Q Tot Post

	Number:	Σ Rank:	Mean Rank:
- Ranks	30	465	15,5
+ Ranks	0	0	•

Z	-4,782	p = ,0001
Z corrected for ties	-4,784	p = ,0001
# tied groups	8	

Wilcoxon signed-rank X 1 : Q Tot Pre Y 1 : Q Tot Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	30	465	15,5
+ Ranks	0	0	•

Z	-4,782	p = ,0001
Z corrected for ties	-4,784	p = ,0001
# tied groups	11	

Wilcoxon signed-rank X 1 : Q Tot Post Y 1 : Q Tot Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	1	2,5	2,5
+ Ranks	8	42,5	5,312

note 21 cases eliminated for difference = 0.

Z	-2,369	p = ,0178
Z corrected for ties	-2,399	p = ,0164
# tied groups	2	

Table A- 2

Statistical results of Questions (Wilcoxon - test)

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	5907.122	203.694	1.885	.0194
Within subjects	60	6484	108.067		
treatments	2	5138.022	2569.011	110.702	.0001
residual	58	1345.978	23.207		
Total	89	12391.122			

Reliability Estimates for- All treatments: .469 Single Treatment: .228

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Exp Tot Pre	30	36.333	11.989	2.189
Exp Tot Post	30	54.033	5.666	1.034
Exp Tot Del	30	49.867	8.617	1.573

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Exp Tot Pre vs. Exp Tot P...	-17.7	2.49*	101.251*	14.23
Exp Tot Pre vs. Exp Tot Del	-13.533	2.49*	59.192*	10.88
Exp Tot Post vs. Exp Tot ...	4.167	2.49*	5.611*	3.35

* Significant at 95%

Table A- 3
Statistical results of Explanations (ANOVA - test)

Wilcoxon signed-rank X 1 : Exp Tot Pre Y 1 : Exp Tot Post

	Number:	Σ Rank:	Mean Rank:
- Ranks	30	465	15,5
+ Ranks	0	0	•

Z	-4,782	p = ,0001
Z corrected for ties	-4,784	p = ,0001
# tied groups	8	

Wilcoxon signed-rank X 1 : Exp Tot Pre Y 1 : Exp Tot Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	30	465	15,5
+ Ranks	0	0	•

Z	-4,782	p = ,0001
Z corrected for ties	-4,785	p = ,0001
# tied groups	8	

Wilcoxon signed-rank X 1 : Exp Tot Post Y 1 : Exp Tot Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	3	21	7
+ Ranks	25	385	15,4

note 2 cases eliminated for difference = 0.

Z	-4,144	p = ,0001
Z corrected for ties	-4,155	p = ,0001
# tied groups	7	

Table A- 4

Statistical results of Explanations (Wilcoxon - test)

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	82.933	2.86	2.738	.0005
Within subjects	60	62.667	1.044		
treatments	2	50.067	25.033	115.233	.0001
residual	58	12.6	.217		
Total	89	145.6			

Reliability Estimates for- All treatments: .635 Single Treatment: .367

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Exer Pre	30	1.233	1.223	.223
Exer Post	30	2.967	.928	.169
Exer Del	30	2.6	.968	.177

One Factor ANOVA-Repeated Measures for $X_1 \ldots X_3$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Exer Pre vs. Exer Post	-1.733	.241*	103.725*	14.403
Exer Pre vs. Exer Del	-1.367	.241*	64.483*	11.356
Exer Post vs. Exer Del	.367	.241*	4.642*	3.047

* Significant at 95%

Table A-5
Statistical results of Exercise (ANOVA - test)

Wilcoxon signed-rank X 1 : Exer Pre Y 1 : Exer Post

	Number:	∑ Rank:	Mean Rank:
- Ranks	29	435	15
+ Ranks	0	0	•

note 1 cases eliminated for difference = 0.

Z	-4.703	p = .0001
Z corrected for ties	-4.838	p = .0001
# tied groups	3	

Wilcoxon signed-rank X 1 : Exer Pre Y 1 : Exer Del

	Number:	∑ Rank:	Mean Rank:
- Ranks	27	378	14
+ Ranks	0	0	•

note 3 cases eliminated for difference = 0.

Z	-4.541	p = .0001
Z corrected for ties	-4.667	p = .0001
# tied groups	2	

Wilcoxon signed-rank X 1 : Exer Post Y 1 : Exer Del

	Number:	∑ Rank:	Mean Rank:
- Ranks	0	0	•
+ Ranks	10	55	5.5

note 20 cases eliminated for difference = 0.

Z	-2.803	p = .0051
Z corrected for ties	-3.051	p = .0023
# tied groups	1	

Table A- 6
Statistical results of Exercise (Wilcoxon - test)

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	10,722	,37	,628	,9141
Within subjects	60	35,333	,589		
treatments	2	13,889	6,944	18,782	,0001
residual	58	21,444	,37		
Total	89	46,056			

Reliability Estimates for- All treatments: -,593 Single Treatment: -,142

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
Q6c Pre	30	2,167	1,053	,192
Q6c Post	30	3	0	0
Q6c Del	30	3	0	0

One Factor ANOVA-Repeated Measures for X_1 ... X_3

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
Q6c Pre vs. Q6c Post	-,833	,314*	14,087*	5,308
Q6c Pre vs. Q6c Del	-,833	,314*	14,087*	5,308
Q6c Post vs. Q6c Del	0	,314	0	0

* Significant at 95%

Table A-7
Statistical results of Question 6 (ANOVA - test)

Wilcoxon signed-rank X 1 : Q6c Pre Y 1 : Q6c Post

	Number:	Σ Rank:	Mean Rank:
- Ranks	12	78	6.5
+ Ranks	0	0	•

note 18 cases eliminated for difference = 0.

Z	-3.059	p = .0022
Z corrected for ties	-3.357	p = .0008
# tied groups	1	

Wilcoxon signed-rank X 1 : Q6c Pre Y 1 : Q6c Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	12	78	6.5
+ Ranks	0	0	•

note 18 cases eliminated for difference = 0.

Z	-3.059	p = .0022
Z corrected for ties	-3.357	p = .0008
# tied groups	1	

There are no valid cases for Column X(1)-Column Y(1).

Table A- 8
Statistical results of Question 6 (Wilcoxon - test)

One Factor ANOVA-Repeated Measures for $X_1 \dots X_3$

Source:	df:	Sum of Squares:	Mean Square:	F-test:	P value:
Between subjects	29	10,489	,362	,603	,9312
Within subjects	60	36	,6		
treatments	2	15,022	7,511	20,767	,0001
residual	58	20,978	,362		
Total	89	46,489			

Reliability Estimates for- All treatments: -,659 Single Treatment: -,153

One Factor ANOVA-Repeated Measures for $X_1 \dots X_3$

Group:	Count:	Mean:	Std. Dev.:	Std. Error:
E6c Pre	30	2,133	1,042	,19
E6c Post	30	3	0	0
E6c Del	30	3	0	0

One Factor ANOVA-Repeated Measures for $X_1 \dots X_3$

Comparison:	Mean Diff.:	Fisher PLSD:	Scheffe F-test:	Dunnett t:
E6c Pre vs. E6c Post	-,867	,311*	15,575*	5,581
E6c Pre vs. E6c Del	-,867	,311*	15,575*	5,581
E6c Post vs. E6c Del	0	,311	0	0

* Significant at 95%

Table A-9
Statistical results of Explanation 6 (ANOVA - test)

Wilcoxon signed-rank X 1 : E6c Pre Y 1 : E6c Post

	Number:	Σ Rank:	Mean Rank:
- Ranks	13	91	7
+ Ranks	0	0	•

note 17 cases eliminated for difference = 0.

Z	-3.18	p = .0015
Z corrected for ties	-3.418	p = .0006
# tied groups	1	

Wilcoxon signed-rank X 1 : E6c Pre Y 1 : E6c Del

	Number:	Σ Rank:	Mean Rank:
- Ranks	13	91	7
+ Ranks	0	0	•

note 17 cases eliminated for difference = 0.

Z	-3.18	p = .0015
Z corrected for ties	-3.418	p = .0006
# tied groups	1	

There are no valid cases for Column X(1)-Column Y(1).

Table A- 10
Statistical results of Explanation 6 (Wilcoxon - test)

APPENDIX II

Examples of the influence on students' wording in Questions and Explanations 1&6 from the software

<u>With reference to the students' explanations in the Pre test</u>

Not only students who explained incorrectly and students who did not explain the questions at all, but also students who explained correctly and completely the questions in the Pre-test were influenced by the software.

1) <u>Students who gave wrong answers and wrong explanations</u>

<u>Questions 1.b and 1.d</u>

In the Pre-test, both students (3M and 6L) ticked the incorrect answer "Stay the same" because of the location of the bulb and they claimed "the resistor R2 is after the bulb so the current entering would be the same".

While in the Post and Delayed-post tests both students ticked the correct answer and they explained correctly their answers, such as :

Questions 1.b and 1.d

"If the resistance in R2 is increased/decreased then the bulb would get dimmer/brighter as the current flowing through the bulb would be greater/smaller" (3M).

"because reducing/increasing resistance increases/decreases the flow of current" (6L).

<u>Questions 6.a, 6.b, 6.c and 6.d</u>

In the Pre test the students (6L, 3M) ticked the wrong answers because of the location of the bulb between the resistors in the circuit and they claimed :

Question 6.b

"In circuit c the bulb is brighter because it is before the resistors" (6L, 3M)

Question 6.d

"In circuit b the bulb is brightest because there is only one resistor before; in circuit a the bulb is brighter than (circuit) c because c has more resistors" (6L)

"In circuit b the bulb is brighter because there is only one resistor before the bulb" (3M)

While in the Post and Delayed-post tests both students ticked the correct answer and they explained their answers correctly, such as :

Question 6.b

"It does not matter which order they (resistors and bulb) are in the circuit, two resistors will have the same effect on the flow of current" (6L, 3M)

Question 6.d

"in circuits a and b the bulb is brighter than in (circuit) c because there are two resistors. For the flow of current it does not matter which order resistors and bulb are in both circuits" (6L, 3M)

2) Students who gave correct answer and wrong explanation

Student 23M claimed "the circuit c has less resistance than the other two circuits so it is the brightest; b and a circuits have equal number of resistors but b is brighter than a"), as mentioned above in the case of student 6L.

While in the Post and Delayed-post tests they answered and explained the question correctly "less resistance increases the flow of current so the bulb is brighter in circuit c; the bulb shines the same in a and b circuits".

3) Students who gave correct answer and no explanation

In the Pre test, students ticked the correct answer either by guessing or by chance and so they could not explain their answer.

While in the Post and Delayed-post tests they were influenced by the software such as e.g. in the question 1.b "the resistance to the flow of electrons increased and so the current decreased and the brightness of the bulb decreased" (1M).

4) Students who gave correct answer and correct explanation

Not only Middle but also High level students, who ticked the correct answers and explained the questions correctly and completely in the Pre test, were influenced by the software because they changed their own wording in the Post and Delayed-post tests.

Middle level students

In the Pre test in the Questions 1&6 students gave explanations in which it was obvious that these students had understood the Ohm's Law in depth and had considered the electric circuit as a system according to the scientific model of reasoning.

However, in the Post and Delayed-post tests due to the provided models and analogies they changed their way of reasoning and so they explained the questions by using this short of terms from which it could be considered that they revealed the influence of the software on their thinking. For instance :

Question 1

a) For the student 4M

In the Pre test in the question 1.b "from Ohm's Law V=i.R, if R2 is decreased V2 will be smaller therefore the voltage across the bulb will be smaller causing the bulb to be dimmer".

In the Post and Delayed-post tests in the question "the R2 resistor controls the flow of current; by increasing the resistance you decrease the current flowing through the bulb (Ohm's law) and so less brightness".

b) For the student 12M

Similarly to the above mentioned, in the Pre test in the question 1.b "again voltage divides in the ratio of resistance and there will be less voltage for the bulb and will cause the bulb to be dimmer".

In the Post and Delayed-post tests in the question "the R2 resistor controls the flow of current; by increasing the resistance you decrease the current flowing through the bulb (Ohm's law) and the brightness is less".

Question 6

a) For the student 4M

In the Pre test in Question 6.a "The bulb in c will be brightest because there are two only resistors in the circuit. That means the voltage across the bulb is greater than in a and b. The a and c circuits are basically the same 2 resistors and 1 bulb changing the position of the bulb will not alter their brightness from the Ohm's Law V=i.R".

In the question 6.c "c will be brighter than a and b as it has less resistance increasing the voltage across the bulb"

In the Post and Delayed-post tests in Question 6.a "circuit c only has two resistors therefore the current flowing through the circuit will be greater and the bulb brighter " and in question 6.c the resistance in c is less than in a and b, resistance in b equal to a. Therefore the current flowing through c will be greater and the bulb will be brighter. The a and b circuits are of the same (total) resistance, so the position of the bulb will not alter their current flow and the brightness of the bulbs".

b) For the student 12M

Similarly to the above mentioned, in the Pre test in Question 6.a "3 resistors in a and b. Only 2 resistors in c, so more voltage across the bulb and more brighter the bulb".

In Question 6.c "Same resistors in a and b, circuit c has less resistance and so bulb is brighter. In a and b the brightness of the bulb is the same, it is not dependent on its position ".

In the Post and Delayed-post tests in Question 6.a and in Question 6.c "the resistors control the flow of current; in a and b circuits were 3 resistors and so less current flowing through the bulb (Ohm's law) than in c. The bulb is brighter in c".

It is worth mentioning that the student 12M gave more negative than positive comments to the Questionnaire and mentioned that s/he "prefer(s) paper and pencil solutions to these problems".

High level students

In the Post test and Delayed-post tests, similarly to students of the Middle level of knowledge background in physics, students of the High level were influenced also by the provided models and analogies in electricity. For example :

Question 1

In the Pre test one student (17H) gave explanations to Questions 1 similar to the above mentioned student's (12M) (Question 1.b "using equation V=i.R if resistance increases then the amperage (i) will decrease. The decreased current will make the bulb dimmer").

In the Post and Delayed-post tests he also used expressions similar to the above mentioned student's (12M), while explaining these questions (Question 1.b "increase of resistance less current flows").

Question 6

In the Pre test one student (17H) gave explanations to Questions 6 similar to the above mentioned student's (12M). However, s/he was the only one of the students who correlated the intensity of current (i) to the power of the bulb (P) and so the brightness of the bulb (questions 6.a and 6.c "the less resistance in the circuit then the more power to the bulb and so its brightness is more").

In the Post and Delayed-post tests also s/he used similar expressions while explaining these questions (questions 6.a and 6.c "the circuit c has the lesser amount of resistance and therefore the bulb will be brightest because of the more current flow").

5) Students who gave no answer and no explanation

In the Pre test only one student (15L) ticked "I don't know" and did not give any explanation to all of Questions 6.

However, in the Post and Delayed-post tests

In Question 6.b "it does not matter which order resistors and bulb are in the circuit, two resistors have the same effects on the flow of current so the brightness of the bulb is the same in all circuits". Such an explanation has also been given by other students (6L, 3M).

In Question 6.a and in the question 6.c "the resistors control the flow of current. The bulb is brighter in c. In a and b circuits there are 3 resistors and so less current flowing through the bulbs (Ohm's law) than in c". A similar response has also been given by the student (12M).

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